A PROTOTYPE TECHNICAL RESEARCH CENTER FOR EXTRATERRESTRIAL EXPLORATION

alfred wallace moffett

submitted in partial
fulfillment of requirements
for the degree of
master of architecture

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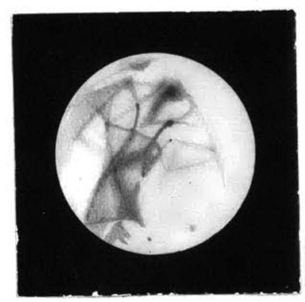

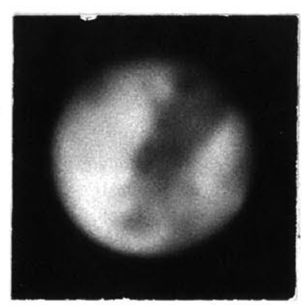

pietro belluschi, dean
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THE PLANET MARS

A Prototype Technical Research Center
for Extraterrestrial Exploration

Alfred Wallace Moffett, B.S. Univ. of Illinois

Submitted to the Department of Architecture
on 16 May 1952 in partial fulfillment of
the requirements for the degree of
Master of Architecture

Since the crossing of the next physical frontier, that of entry into the vastness of Space, may occur in the near future, an investigation of the conditions confronting Man there is pertinent. Before any utilization of the resources of other planets would be possible, more data are required, and this project is a proposal for a Research Center for exploration of other worlds.

Although Man has been able to modify his environment to a considerable degree, it is only within the pattern established by nature, and these conditions are first set forth to determine the requirements for life. Temperature and oxygen are found to be of vital concern, and against this base, conditions prevailing on the other planets are contrasted. Mars and Venus are the only two on which most authorities feel life may exist, though Mars is the only one showing any indications of the presence of life. A survey of the data known or surmised from study of Mars reveals a temperature-range not impossible for Man's existence if protected, though the natural oxygen level is too low to support intelligent life. Other information pertinent to the establishment of the base there is summarized.

To determine the period available for a preliminary survey, the means of transportation to other planets indicates that a period of 449 days is necessary before a return to Earth could be attempted economically. To operate within this interval, a tentative organization of 33 men is set up, to work on specific phases in the fields of biology, geology and meteorology.

Due to the presence of an extremely thin atmosphere, any structure housing Man is subject to an internal pressure of 1950 psf against the enclosing surfaces. Rather than resisting this, which would require heavy members, use is made of the pressure to form the walls

and support the internal floors of the structure. To enable easy and rapid erection of this shelter, a portion of the craft transferring personnel to the surface from the ships in satellite orbit about Mars is utilized as the central unit of the Center. From this three shells of reinforced plastic are expanded and shaped by internal pressure. Equipment packed within the central core can then be transferred to its point of use. Within each shell, the lower floor contains sleeping quarters, while the upper level of the three contain the operating functions of the base, the laboratories and work areas of the personnel.

Heating is accomplished by means of a ring of ducts absorbing solar energy, which is transferred to containers of Glauber's salt for storage until required. Food, water and oxygen requirements are satisfied against the requirements of the personnel. Power supply for the operation of the equipment is found to be a critical item, but use of winds existing on Mars enables power to be obtained from wind-generators.

A portion of the operations are carried on in sub-bases removed from the Center, and by automatic units communicating their data to the Center by radio.

Thesis Supervisor: Pietro Belluschi

Title: Dean, School of Architecture and Planning

The Graduate House
Cambridge, Mass.
16 May 1952

Pietro Belluschi, Dean
School of Architecture and Planning
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Dean Belluschi:

In partial fulfillment of the requirements for the degree of Master of Architecture, I herewith submit this thesis, titled "A Prototype Technical Research Center for Extraterrestrial Exploration."

Sincerely yours,

Alfred Wallace Moffett

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I wish to express appreciation and gratitude to those members of the faculty who gave valuable assistance, wise counsel and helpful criticism, and to the members of the Graduate Class in Architecture for enlightening discussion.

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By the end of the next decade it is quite possible that Man may have taken his first actual step toward extending his dominion into the rest of the Solar System. Scientists and engineers of several disciplines now working on allied problems, estimate that in that period we could build an artificial satellite to circle about the Earth. There seems little doubt that we have today the essential materials, machines, and skills necessary to dispatch Man into the waste spaces of the heavens.[1]

Due to the natural characteristics of the Earth's gravitational field, reaching the orbit of this satellite will consume the major energy-portion of the journey not only to the Moon but to the nearest planets, Mars and Venus. Thus it is that with this step accomplished, the rest should follow shortly, if we wish it. However, before utilization of the possible resources of these planets could be obtained, much more information will have to be obtained. For this reason, it is likely that the first men to set out for an actual landing on another planet will be scientists and technicians, trained and equipped to obtain such pertinent data as is possible. This project is intended to serve as a preliminary investigation of the problems involved

1. Harland Manchester, "The Astronauts Are Serious," Harper's Magazine, May, 1952.

in establishing such a base, and as an indication of several possibilities of their solution.

In view of the tremendous difficulties facing such an expedition, of which some will become apparent in this discussion, it may well be asked: what is to be gained by this endeavor? In the face of the conditions confronting Man once he has left a planet so well adapted to Life, is the effort worth while?

There are several motivations driving men toward the realization of space travel. First is the everseeking curiosity of Man, the desire to see beyond the horizon. This was part of the force behind many in the past, from Columbus through Boone to Byrd. "An expedition is the inspiration generated in the soul of a leader, an inspiration born of a desire for adventure and the achievement of daring feats. From this desire to tread where no one else has trod, he selects an area new and inviting which has a multitude of geographical and other scientific problems to be solved."[2]

Thus related to the first drive is the second, the desire for knowledge, and it is this which bids fair to justify an endeavor of this type. For out of the

2. Paul A. Siple, "Adaptations of the Explorer to the Climate of Antarctica," p. 287.

seeking for the means to attain this purpose will come much that might enrich our lives; from the knowledge that results from the expedition itself may come an unforeseeable good. The potentialities of the future are vast, and we know not which way to seek them nor indeed do we know, in many cases, that which we seek. When asked of the worth of his discovery of some of the effects of electricity, Faraday is said to have replied, "Of what value is a newborn babe?"

Conditions Required for Life

One of the characteristics separating Man from the other animals is the extent to which he has been able to adapt his environment to his needs and desires, rather than adapting himself to meet external conditions. Typical of that response is the convoluta roscoffensis of Brittany, whose life-cycle is based on the interplay of sunlight and tidal motions. Yet, despite his adaptability, Man yet remains subject to bioclimatic necessities. Though he is capable of modifying much of the natural environment to suit his desire, it must be changed to accord with the pattern nature has established within him, and in most cases, within living creatures generally.

The conditions under which life exists on Earth have been studied intensively, and it is believed that similar conditions must prevail on other planets if life is to be possible. The forms developed might well be different were life to exist on other planets due to variations in the evolutionary conditions, just as, to a lesser degree, creatures of the Pacific islands vary from related species on the mainland from which they were early isolated. From examination of the conditions here can be determined the feasibility of existence elsewhere.

Throughout the visible universe, the same chemical elements are present, and generally, though there are exceptions, the same relative abundance of each element is to be found. Since the same laws of structure prevail also, it follows that the chemical laws will be universal, and carbon compounds will in all likelihood be the foundation of the chemistry of living matter. From the nature of these compounds certain limitations are set on the capacity of a planet to support life. Factors of temperature, radiation, and the presence of the bio-elements are most important, but these must occur only within certain limits.

Living matter, composed of generally complex compounds, is rather fragile, and an increase in temperature beyond a certain point results in destruction. The active phenomena, metabolism, muscle-nerve activity, reproduction, etc., occur from just below 0°F. to 140°F.[3] Above this temperature most life soon perishes, from dehydration, coagulation of protein material, and blocking of enzyme action. In Man, the normal range of temperatures capable of being balanced by the body control mechanisms

3. Hubertus Strughold, "Considerations on the Possibility of Extraterrestrial Life," p. 33.

is from 80° to 105°F.; there is some evidence that the lower limit may, under certain circumstances, be as low as 60°F. Below the minimum temperature required for active life, is a zone of danger, though here the exceptions of certain organisms, both plant and animal, which are capable of becoming merely dormant during periods of temperatures approaching even absolute zero, demonstrate that life cannot be ruled out should such levels exist. It is difficult to believe life could exist should a planet never reach the minimal point.

Through the interplanetary space beyond the Earth's atmosphere moves a considerable quantity of material, though the density is quite low. The particles attracted toward our surface range in size from the largest (meteors) to the smallest (microwave cosmic rays). Most of this bombardment is absorbed or filtered by the various constituents of the atmosphere: by far the greatest proportion of the meteors entering the atmosphere are destroyed as a consequence of their velocity, which may range between 11.1 km./sec. and 73 km./sec. The atmosphere selectively filters the radiation particles, with only three bands being allowed through: extreme X rays, the visible spectrum, and short radio waves.[4] The other penetrations are impeded by the oxygen,

4. Konrad Buettner, "Bioclimatology of Manned Rocket Flight," p. 75.

ozone, nitrogen, water, and carbon dioxide present. This effect is of prime importance in the consideration of the other planets.

However, the short X rays in their passage through the upper atmosphere give birth to secondary and tertiary radiation, some of which is absorbed, but some of which continues through to penetrate our bodies. The intensity increases as we ascend through the air, only to decrease above 60,000 feet. What effect increased radiation will have on our bodies is not known at present. In any event, only a yard of lead is effective, since a thin shield produces the secondary emissions.

Ultraviolet radiation, though easily stopped by opaque walls, remains a problem where vision is necessary. The biologically important range is that below 32μ, where extreme radiation affects the cells of the skin directly, possibly acting on the cell nucleus; acute forms may lead to skin cancer.[5] The most effective bactericidal region is in the range 25μ to 26.5μ, the reaction causing death being produced inside the cell. Despite the lethal effects, bacteria do exist within this range, however, as aerosols. It may be, however, that shielding is provided by the particles supporting the bacteria.

5. Konrad Buettner, "Physical Aspects of Human Bioclimatology," p. 1123

Accompanying this radiation is that of the visible spectrum. All life depends on light; it is by this means that energy is obtained from the Sun. Animals obtain most of their chemical requirements from their food: either from vegetation directly or from animals fed on vegetation. Since much of the radiation is reflected by the surfaces of the plants, vegetation is remarkably inefficient in its absorption of solar energy, and the loss is compounded if meat is the intermediate step.[6]

Water is also a vital substance. There are many reasons for supposing that life arose in water, and many of the evolutionary changes in life-forms are the result of adaptation to other environments. Water forms 70% of the weight of man, and the loss of 10% will result in illness, the loss of 20% in death. It functions ideally as a solvent, carrier of body foods and wastes, and as a regulator of body temperature. The relative humidity of the air about him bears a great relation to the temperature he can stand.

While the chemicals necessary for life vary somewhat with each species, thirteen elements are commonly found in all. Oxygen, carbon dioxide and hydrogen are the

6. Eugene Ayres, "Energy Sources," p. 240.

most vital, for from these protoplasm can be formed. Oxygen forms 60% of all living matter, and the most important source of energy is biological oxidation. A certain concentration, varying with each species, of oxygen in the medium surrounding the organism is required. Certain worms and bacteria exist under special conditions without oxygen; lower animals such as frogs and crabs can exist for periods at only 10 mm. Hg to 1 mm. Hg. The minimum oxygen pressure for man is 65 mm. Hg, although efficiency is handicapped at levels below 100 mm. Hg. The blood, carrying food and oxygen, must attain a minimum of 80% saturation with oxygen, as it passes through the lungs. In order for this to happen, the inhaled air must have an oxygen pressure of 133 mb., equivalent to that found at an altitude of about two miles. A reduction in barometric pressure alone may cause discomfort and distress.[7]

The level of carbon dioxide concentration is not definite; there is some evidence that plants would be more efficient at higher concentrations than are present in normal air, while much higher concentrations have a serious effect on men. Plants can exist without oxygen if necessary since they can synthesize it from carbon dioxide.

7. Konrad Buettner, "Physical Aspects of Human Bioclimatology," p. 1121

Consideration of the Planets

Through consideration of the criteria represented above, it is possible to determine from an analysis of the data obtained from observation of the other planets the probability of the existence of life, within broad limits, and the suitability there for us. Calculations based on the data presented in Figure I enable astronomers to predict what elements might have been retained to form an atmosphere; in some cases, analysis of the reflection-spectra of the planets corroborates these assumptions, though several elements, hydrogen, nitrogen and argon, cannot be discerned, since their absorption bands are masked by the Earth's upper atmosphere. Presence of an atmosphere may be indicated by cloud phenomena, twilight, refraction phenomena, or darkening of the limb of the planet's image. Temperatures can be obtained, of areas of about 200 miles in diameter, by radiometric observation.

The closest object in the heavens is of course the Moon, and it is to it that many expect the first interplanetary flight, other than to the artificial satellite. Although some British and Continental observers still believe in an atmosphere there, though most tenuous, analysis here can find no trace. Were that objection

Figure I

The Solar Planets

Body	Mass Earth=1.0	Radius Earth=1.0	Density Earth=1.0	Gravity Earth=1.0	V_{escape} km/sec.	Distance from Sun Earth=1.0	$V_{orbital}$ mi./sec.	Year Earth=1.0	Surface Area Earth=1.0
Mercury	0.045	0.39	0.76	-	3.8	0.387	30	.24	0.14
Venus	0.82	0.973	0.89	0.86	10.4	0.723	22	.61	0.91
Earth	1.0	1.0	1.0	1.0	11.3	1.0	18.5	1.0	1.0
Moon	0.0123	0.273	0.607	0.16	2.4	-	-	-	0.07
Mars	0.108	0.532	0.70	0.38	5.1	1.524	15	1.88	0.28
Jupiter	318.35	10.97	0.241	2.64	61.0	5.203	8	11.86	120.0
Saturn	95.3	9.03	0.13	1.17	36.7	9.539	6.5	29.46	8.4
Uranus	14.58	4.00	0.23	0.91	21.6	19.19	4	84.02	15
Neptune	17.26	3.90	0.29	1.12	23.8	30.07	3.3	169.8	17
Pluto	0.93	1.0	0.9	?	11?	39.46	3	247.7	0.2

Principal Components of Atmosphere

Mercury	--
Venus	CO, CO_2, N_2O, CH_4
Earth	N_2, O_2, CO_2, O_3
Moon	SO_2
Mars	CO_2, N_2O, CH_4, NH_3
Jupiter	CH_4, NH_3
Saturn	CH_4, NH_3
Uranus	CH_4
Neptune	CH_4
Pluto	?

to be overcome, as it may, the lack of one leads to other deterrents to habitation there: lack of atmospheric shielding from both radiation and meteors. Though impacts of bodies have not been observed (and the likelihood of doing so is slight), general indications tend toward the theory of a continual pitting of the surface by meteoric masses. Having no atmosphere, the temperature-range of the surface is extremely broad, from 240°F. in the two-weekly "daytime" to -84°F. at the beginning of total darkness to a minimum of -160°F. at the end of the dark period.

From the impact of meteoric matter and from thermal erosion, the surface should be similar to pumice dust, seemingly confirmed by recent observations. Possessing high insulation qualities, this would allow comfortable temperatures just below the surface. Establishing a base underground thus would provide protection from temperature as well as radiation, but would involve the use of earth-moving equipment. Economic justification for such a move might be found in the production of fuel[8] and in the raw materials there. However, in view of the construction difficulties, I did not feel such an establishment to be feasible as a first base. Many

8. G. V. E. Thompson, "The Lunar Base," Journ. Brit. Int. Soc., March, 1951.

of the functions assigned to such a base can more readily be handled on the satellite vessel.

The first of the planets from the Sun possesses similar disadvantages. As does the Moon, Mercury revolves about its "mother" in the same period as its rotation about its axis, so that the same face is presented to the Sun at all times. A slight wobble in its rotation leads to a twilight zone, where equable temperatures are found, but the range from 770°F. on the sunward side to -450°F. on the dark side, coupled with the lack of an observable or probable atmosphere, tends to preclude the possibility of life existing there. Should it be desirable, bases could be set up in the twilight zone, but life there would indeed be difficult.

Venus, the second planet, is a shrouded globe, clouds completely veiling the surface. Its size makes it almost our twin, but other similarities are missing. Since its surface has not been seen, rotation can only be assumed from the normal temperature variation between the dark and sun-lit sides, -9°F. and 130°F. Although the carbon dioxide content seems to be about 500 times the amount present in the Earth's atmosphere, no appreciable trace has been found of oxygen and water vapor. Having an assumed rotation of at least three weeks, strong winds undoubtedly exist at the surface due to the temperature differential between the sun-lit warm side and the dark side. The clouds, of dust or condensed carbon dioxide, probably induce a greenhouse effect at the surface, with temperatures estimated at 212°F. There is a possibility that bacterial aerosols may exist at certain strata of the atmosphere where suitable conditions may exist.[9] Settlement there, while possible, would be under great handicaps.

Skipping to the planets beyond Mars, temperature is the first consideration which eliminates them. Jupiter, the nearest, has been measured at -212°F.; the others are even colder, thus far below the minimum level for continued life. The major planets are massive enough to have retained hydrogen, although it cannot be detected. The compounds of ammonia and methane have been identified. The actual surface of the planets has not been seen. The large gravitational attraction of Jupiter makes it unlikely it will be visited for a reasonable time. Pluto, the farthest out, is small, though observation difficulties preclude the assignment of definite values to any characteristic.

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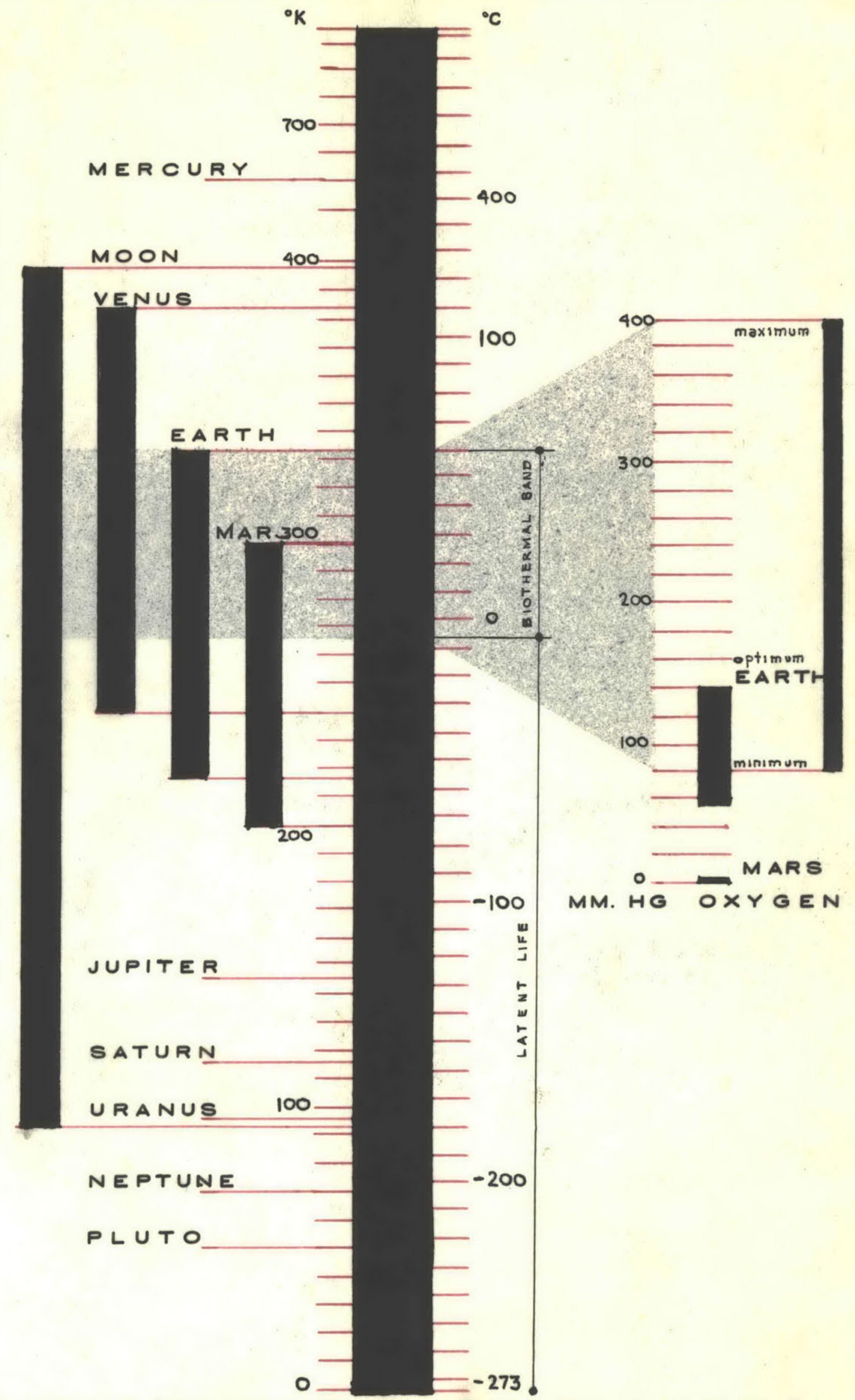
9. Heinz Haber, cited in Strughold, "Life on Mars in View of Physiological Principles," p. 3.

Conditions on Mars

The remaining planet to be examined is Mars, the fourth from the Sun. Because of its nearness, it has been the subject of much observation, even though this is handicapped by several factors. Great patience on the part of many observers has built up a body of considerable data, and has also led to much speculation and excitement concerning the existence of intellectual life there. It will be seen from the forthcoming data that this is highly improbable. From the chart, Figure II, it will be seen that its upper range of temperatures lies within the biothermal band, although the lower two-thirds is into the zone of latent life. Since these temperatures represent not only a geographic spread but also the daily variations, life there would need to be able to withstand rapid changes of temperature over a wide range. Oxygen, though present, is in such meager supply as to be unusable by the higher animals or by man.

Mars has a mean orbital distance from the Sun of 142 million miles, with an orbit of greater eccentricity than the Earth's. Because of this variation, its minimum distance from the Earth changes from 35 million miles to 49 million, a factor of importance in the



TEMPERATURES OF PLANETS

calculation of an orbit of a ship moving between them, as well as increasing the difficulties in studying it. With a diameter of 4200 miles, it is but half of Earth; its surface area is thus one-fourth. However, since it has no oceans, the land area is approximately the same. Having a mass of but one-tenth that of Earth, its gravitational constant is but 0.38 g., which has influenced its ability to retain atmospheric components. The journey about the Sun takes 687 Earth-days, which are slightly shorter than those on Mars: 23 hours 57 minutes to 24 hours 37 minutes. This variation should have little effect on humans living there.

Mars is similar to Earth in the tilt of its axis with reference to the plane of its orbit, so that the seasons, though longer, resemble ours. There are two moons, both quite small. Phobos, smaller of the two, is only 5000 miles from the surface and sweeps across the sky in its orbit of only seven and one-half hours. Deimos, about 40 miles in diameter, is farther out, and takes a more circumspect 30 hours and 18 minutes to circle the planet.

Seen through a telescope, Mars seems an orange disc, with blue-green areas marking its surface along with white caps at either pole. Both these areas undergo seasonal and seemingly coordinate changes, the blue-green changing to a chocolate and thence back, as the polar caps alternately increase and diminish in size. The darker areas remain essentially stable in location and shape. These changes have led to the interpretation of the growth of vegetation as the polar snows melt. Other markings, linear in nature essentially, have been photographed, though greater detail is possible in visual observation by trained personnel.

For the purposes of this study, the composition of its atmosphere is one of the most important factors. Despite its low gravitational attraction, which would permit the escape of hydrogen and helium, some constituents could be expected to remain. Photographs taken at Lick Observatory through infrared and ultraviolet light definitely establish the presence of an atmosphere, with an approximate depth of 60 miles. The atmosphere is transparent for visible and infrared light, with an optical thickness about one-third that of Earth. However, analysis of its chemical composition is rendered difficult by the presence, in any spectrum obtained, of strong telluric lines for the same elements.

There are three essential means of evading this hindrance: measuring the change in intensity of the lines over that for our atmosphere alone, measuring the displacements in the lines from the normal position, and by changes in their shapes.[10] By these methods it has been calculated that the upper limit for the ratio of Martian oxygen to that in our atmosphere is 0.0015, with similar figures obtained for water vapor also. Carbon dioxide has been determined at approximately twice that of Earth; argon, though undetectable, is expected there, possibly from the decay of radioactive potassium in the surface materials. Nitrogen, also undetectable, is expected, since it is relatively abundant generally, is heavy enough to have been retained, and is chemically inert. Neither methane nor ozone have been detected.

Though water vapor has been estimated at such low quantities, several factors point to its presence: the polar caps, by examination of their infrared reflection spectrum, compare more favorably with frost than with dry ice, and the temperatures at the poles are not low enough to maintain carbon dioxide in a solid state. Calculations of the surface pressure of the Martian atmosphere, from several approaches, agree; since one

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10. Theodore Dunham, Jr., "Spectroscopic Observations of the Planets at Mount Wilson," p. 294.

was made on the assumption of water vapor being present, its presence is more firmly indicated. The pressure thus determined was 80 mb., or about 1.2 psi., corresponding to an altitude on Earth of about 55,000 feet. The possibility of the existence of large bodies of open water is rather remote, on the authority of a leading Russian astronomer, Fessenkof.[11] The low temperatures tend to prevent it, and in any event, none have been observed. From effects of light-reflection, it would be possible to detect ponds of 1000 feet diameter, were they to exist. The polar caps are the main repository of water on Mars, even though their thickness has been calculated at only 10 cm.

Clouds of two main types have been observed. White clouds are seen visually occasionally and also appear in ultraviolet photographs over the snow caps. Yellow dust clouds appear, sometimes of such dimension as to change the color of the planet. Besides these clouds there is a semi-permanent veil which obscures the surface under blue light; its nature is unknown, though it has been suggested that it be crystals either of water or carbon dioxide.

The lack of oxygen and the greater presence of carbon dioxide tend toward a low temperature, already lower

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11. Reported in Astronomical Newsletter, No. 48, March, 1950.

than Earth's because of its greater distance from the Sun. However, the thinness of the atmosphere, as well as differences in the surface materials allow Mars to absorb a greater portion of the incident solar radiation. By this means, although Mars receives but 44% of our radiation, it is able to use and absorb 61% of that utilized by Earth.[12] The most suitable set of temperature data was that obtained by Coblentz and Lampland in 1926, which was used for Figure III. Normally, temperatures near the equator at sunrise are about -4°F., rising to about 68°F. at noon, dropping to 40°F. by sunset, and to about -20°F. during the night, though the minimum temperature is lower than that. Loss of heat from the planet at night is impeded by the presence of clouds, which dissipate shortly after sunrise.

From the above temperature-distribution data, and from observation of cloud movements, it has been possible to delineate broadly the pattern of the winds, as shown in Figure IV. Generally, the pattern is similar to terrestrial winds, although the average velocities are estimated to be lower. Winds of from 10-20 mph are known to exist on the surface, while Hess calculates winds of 30 mph would be required to transport the moisture from pole to pole at the change of seasons.[13]

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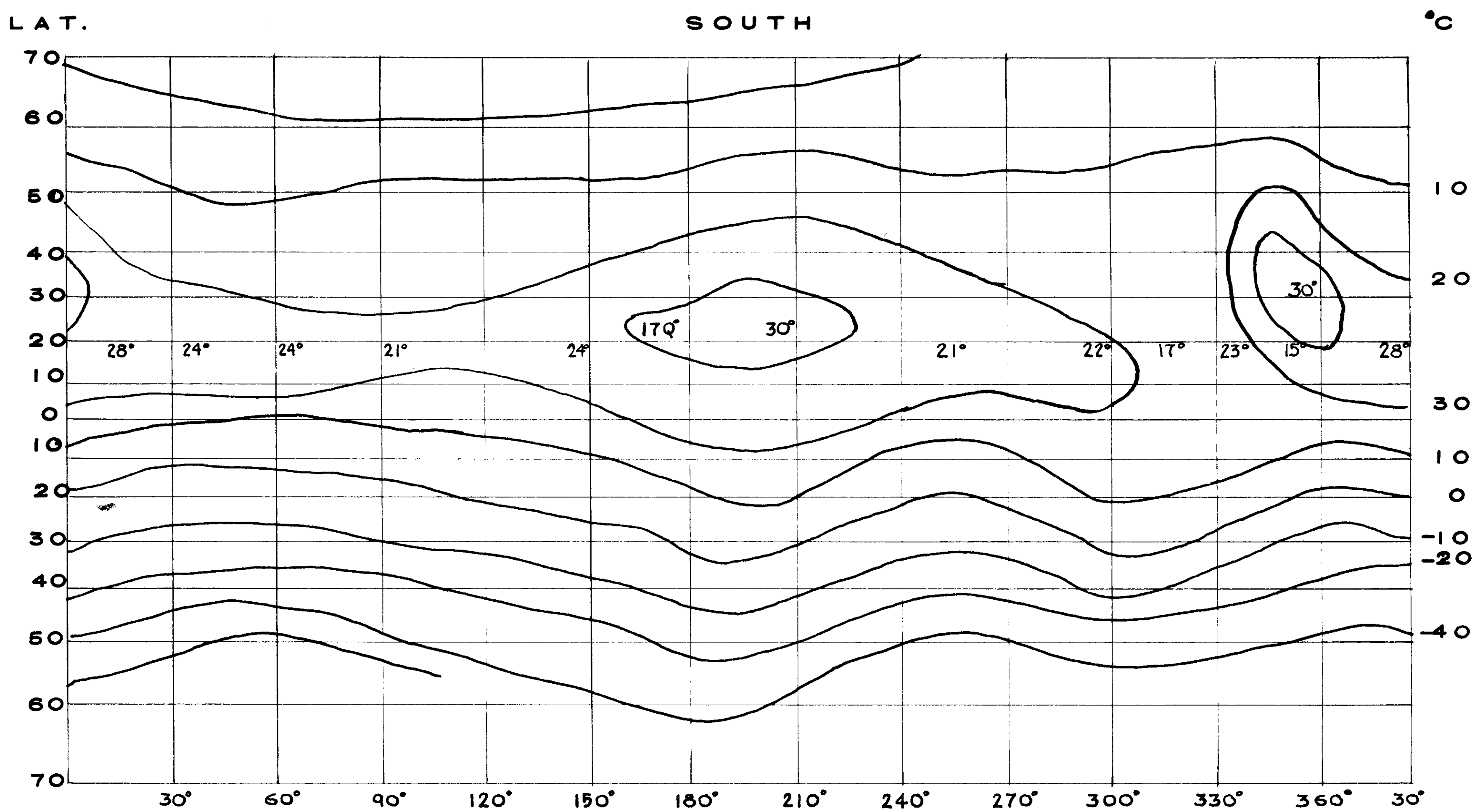
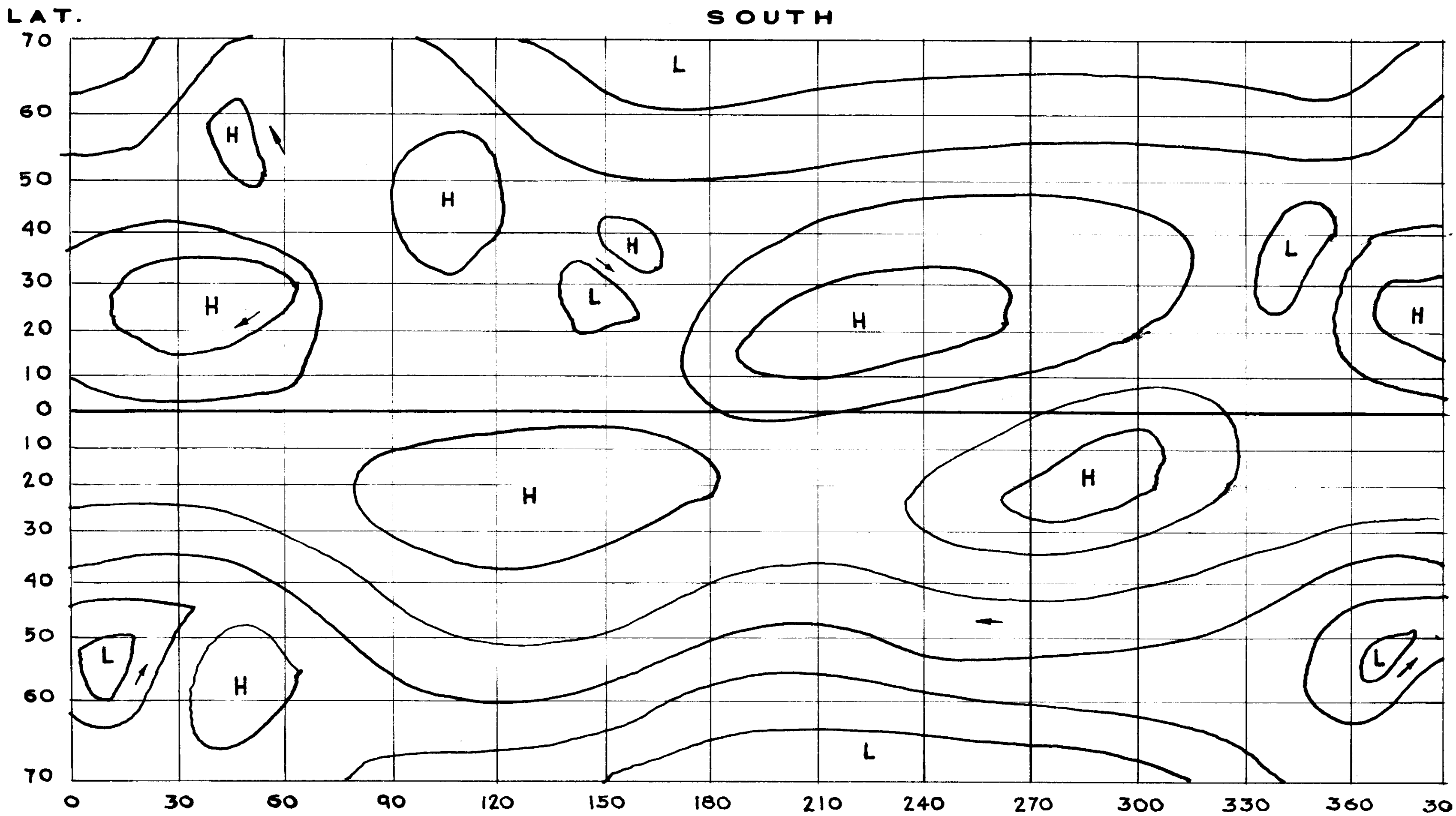
12. Seymour Hess, "Some Aspects of the Meteorology of Mars," Journ. Met., February, 1950.
13. Ibid.



DISTRIBUTION OF TEMPERATURES ON MARS

DURING NORTHERN HEMISPHERE WINTER AFTER S. L. HESS



SCHEMATIC STREAM-LINE MAP OF MARS

DURING NORTHERN HEMISPHERE WINTER AFTER S. L. HESS

The nature of the surface of Mars has been the subject and cause of much speculation in the past. From comparison of the reflection spectra of the "desert" areas with those of terrestrial soil and rocks, Kuiper believes the material to be igneous in nature, similar to felsite, a fine-grained type, rather than ferrous oxide as formerly assumed.[14] Under the former theory, the oxygen on Mars oxidized the iron in the soil and in this way both the water and oxygen in the atmosphere disappeared. Opposed to that, besides Kuiper's investigations, are the calculations by Coblentz and Lampland which led to the assumption of a general distribution of a silicate granite-like material; the proposition by Spitzer that oxygen formerly present in the atmosphere would have escaped due to the higher temperatures existing were more oxygen present;[15] and the conclusion by Tombaugh that Mars has always had a similar structure and atmosphere.

From a geological consideration, Tombaugh[16] feels that Mars exhibits the appearance of a planet subject to the deformation occasioned by a shrinkage in volume after the formation of a thick crust. The "oases" and "canals" forming a linear pattern over the surface, without regard

14. Gerard Kuiper, "Survey of Planetary Atmospheres," p.335.
15. Lyman Spitzer, Jr., "The Terrestrial Atmosphere Above 300KM," p. 246.
16. Clyde Tombaugh, reported in Astronomical Journal, October, 1950.

for changes in color or texture, could thus be the result of impacts of asteroids on the surface. The fracturing resulting appears as the canals, through the growth of lichenaceous plant life in the soil produced in the cracking, while the lack of water erosion would permit the evidence of long ago to remain. Only the wind erosion suggested by the dust clouds would tend to soften the impact. Because of optical limitations, only details approximately 18 miles in width would be visible. Urey[17] has estimated, on the basis of calculations based on rotational data, that Mars is of fairly uniform density. During geological ages, while the Earth was hot enough to melt iron, which then flowed to the core, Mars was too cool for this change. It has remained as a fossil planet demonstrating Earth's past. With all these effects, Mars is assumed to be a relatively smooth planet. Although variations in altitude of about 2-3000 feet appear to occur, there are no discernible peaks, and the breaks are in line with Tombaugh's deformation theory. Were greater peaks to exist, they should be apparent at the edge of the disc, at the terminator between light and dark, and through shadows.

17. Harold C. Urey, "Structural and Chemical Composition of Mars," Phys. Rev., October, 1950.

More spectacular effects are to be seen in the blue-green areas; going from green to chocolate and back early suggested vegetation,[18] though some mineral salts could exhibit such changes also. These areas have been examined closely with the spectroscope. The analysis is consistent with that of lichen and certain mosses on Earth. Being a simple symbiotic life-form, lichenaceous plants could exist there, despite the temperature range, the composition of the atmosphere, and the lack of moisture. From the discussion of life requirements, it seems impossible for higher life to survive, and it is fruitless to discuss the possibility of the existence of low forms of life that might. Any life would probably be photorhythmic, active after sunrise, returning to dormancy with night. "We can only conclude that the climates of Mars are not very different from those of Earth, and only a little more rigorous on the average; but that the variations in temperature from day to night, and from winter to summer in the Polar zones, are much more pronounced."[19] Some observers have compared the general effect to that of the upper regions of Tibet.

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18. Fred L. Whipple, "Earth, Moon, and Planets," p.
19. Gerard de Vaucouleurs, "The Planet Mars," p. 59.

On Interplanetary Travel

Although a great deal is known or surmised about the nature of Mars, it is largely on a planetary scale, since local conditions are not discernible except by intuition. To obtain more definite and specific knowledge it will be necessary for men to go there and gather the data, in the manner of expeditions to the less familiar areas of the Earth. For this reason, it is pertinent to examine briefly the means by which they will be able to travel through space.

The most important obstacle to be overcome is the gravitational field of the Earth, although for interplanetary travel, the influence of the Sun also must be considered. Theoretically, the Earth's influence extends to infinity; practically it cuts out at about 4000 miles above the surface. Since the field weakens as the square of the distance, it may be pictured as resembling an inverted wineglass stem. As you go further out, traveling becomes easier. The velocity necessary to escape this attraction may be attained either by a slow continuous pull (actually impossible to attain in practice) or by having an initial push sufficient to allow you to coast up the slope. At the surface of the Earth this amounts to about 25,000 miles per hour, or 11.2 km./sec.

A rocket motor is the only type of prime mover presently developed that will be capable of traversing space, because of its independence of the medium in which it moves, and by the thrusts it is able to develop.[20] The velocity a rocket is able to attain is dependent on the exhaust velocity of the gases and the amount of fuel ejected. A prime consideration thus becomes the mass-ratio of the rocket, the ratio of the final mass of the ship, after its fuel has been burned, to the initial mass. To attain a velocity equal to the exhaust velocity is no problem, but the maximum practical value is likely to be about double. With present-day fuels and materials we have achieved values approximately 2.5 km./sec., or a final velocity of about 5 km./sec. Theoretically, higher velocities are obtainable, but they are as yet limited by the temperature-characteristics of the materials used for construction. With this velocity, a mass-ratio of about 100 is required, about ten times the limit practicable. It can be seen that for the present, a single chemically propelled rocket could not attain the velocity necessary for escape.

Overcoming this dilemma may be accomplished by two techniques: a multiple-stage rocket and splitting the journey into several stages. The use of a multiple-stage

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20. Arthur C. Clarke, "Interplanetary Flight," p. 21.

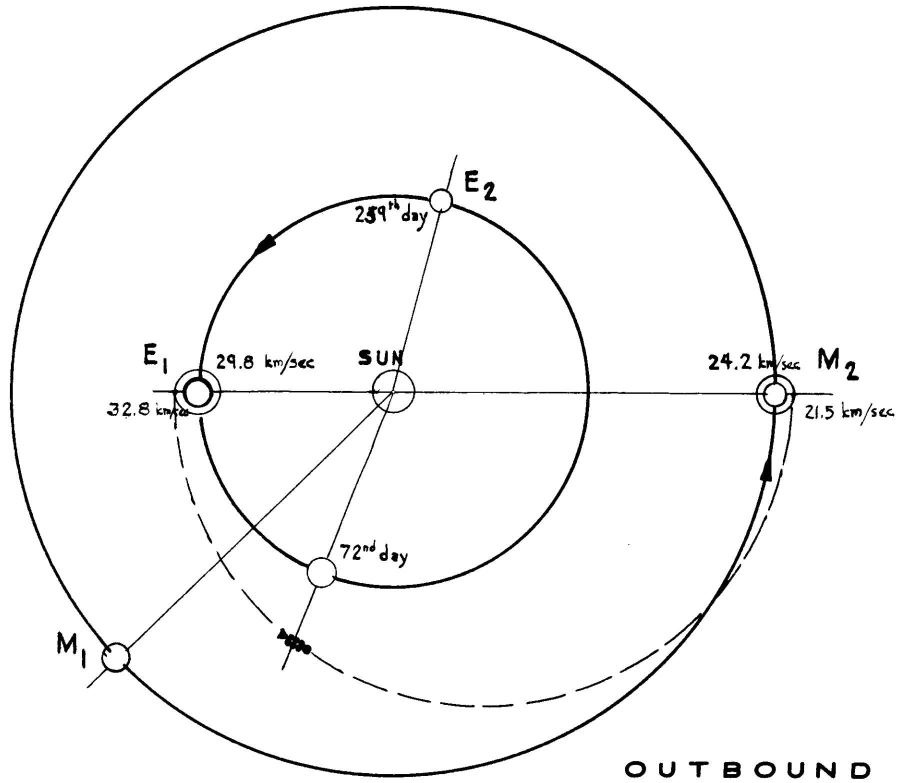
rocket allows us to develop greater velocities than the restriction above, since each successive stage has as its initial velocity the final velocity of the previous unit. If the payload of one rocket were yet another rocket which in turn carried a third, the final velocity would be three times that of the first. As each stage is exhausted of fuel, it is jettisoned, allowing its "load" to continue. For this reason it has been proposed that the launching sites be located near the ocean to allow easy recovery of the discarded units.

Dividing the journey into several stages is accomplished by setting the ship into a satellite orbit about the Earth. If the proper velocity is selected for the altitude desired, the centrifugal force developed will balance the gravitational attraction, and the ship will circle ceaselessly in its orbit, just as does the Moon. As it circles, others can join it, and the construction of another type ship may be undertaken. Since the orbit chosen would best be outside the atmosphere (to avoid resistance of the air), this craft need have no shell:[21] the components merely being tied together: personnel-cargo unit, fuel tanks, and motor. After assembly and the transfer of personnel and cargo, this vessel leaves the orbit and with only a slight increase in velocity

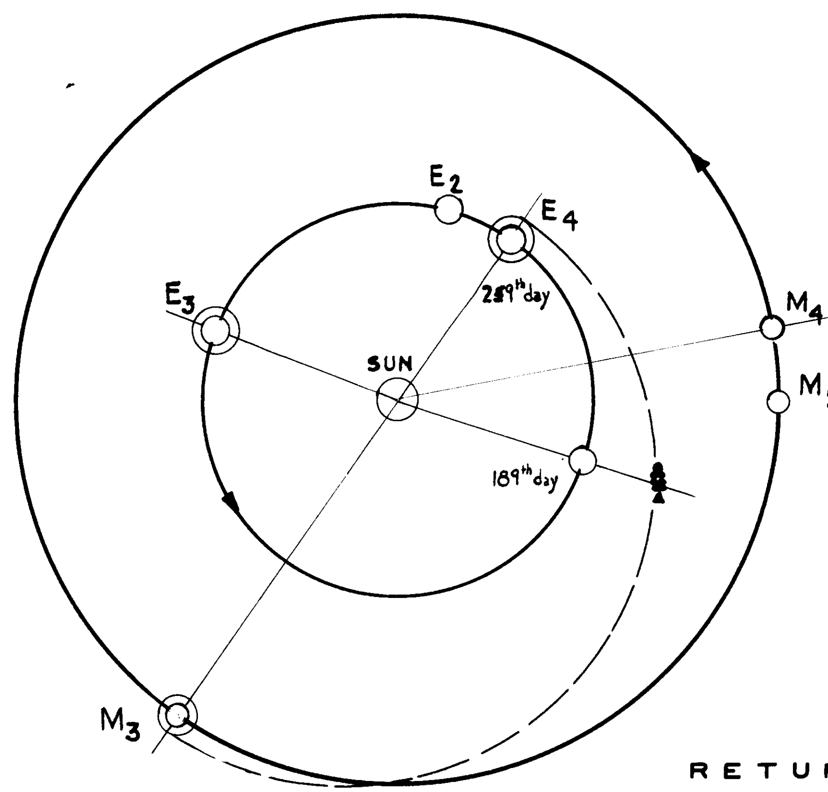
21. Wernher von Braun, "Mars Project," p. 115.

escapes the Earth into space. Here it becomes a planetary body, subject to the same astronomical laws as the others. Its movements between the planets are governed by the gravitational attraction of the Sun as balanced by its own velocity, resulting in an orbit which will have been calculated to intersect with that of its destination, preferably at a time coinciding with the desired planet. There it will enter a satellite orbit about this planet, and ships similar to the ones between Earth and the interspace vessel will ferry the group and its equipment to the surface.

The orbit chosen between Earth and another planet will depend on the time desirable for the trip. At present, since fuel is a vital problem, it is probable that the most economical would be selected; the orbit shown in Figure V has been calculated on this basis for the trip to Mars. For a ship to leave the orbit of Earth to travel to Mars, it must have a velocity of 32.8 km./sec., which will decrease through the trip to a value of 21.5 km./sec. Since the Earth is moving with a velocity of 29.8 km./sec., only 3.0 km./sec. need be added; however, this is in addition to the escape velocity of 11.2 km./sec. previously discussed and the final escape velocity is 11.6 km./sec. (the addition is of kinetic energies, not an arithmetic procedure). From the surface



OUTBOUND



RETURN

PATHS OF FLIGHT TO MARS

of the Earth this would be impossible, even for a three-stage rocket. If, however, we establish a satellite orbit at 1075 miles above the surface, the velocity of ships there would be 7.07 km./sec. Thus the interplanetary ship would need only add a velocity of 3.31 km./sec. to escape the Earth into the proper orbit to Mars, taking 259 days for the transit. Thus we see that reaching the satellite orbit would have placed behind us over two-thirds of the fuel requirements for the voyage to Mars, if only one vessel were concerned. Actually, the assembling of the orbital ships, their outfitting and loading will require many flights from the surface to the orbit of supply vessels, so that an even greater portion of the fuel is consumed in this first stage.

Upon reaching Mars, the ship would be moving at a velocity of 21.5 km./sec. from the loss to the Sun's attraction. Mars, however, is moving at a velocity of 24.1 km./sec., so an additional 2.01 km./sec. must be added to place the ship in an orbit 600 miles above the surface of Mars. Here the orbital ships would circle, while landing craft transferred those of the expedition to the surface. The return trip to Earth would involve the same velocity changes, in reverse, and the same length of time, since the orbit of the ship is an ellipse. However, since Mars and Earth move about the

Sun in different times, 687 to 365 days, a period of waiting in the orbit of Mars of 449 days is necessary until conditions similar to those of the outward journey exist between Mars and Earth. For this reason, then, the period of time alloted to this group for their investigation of Mars has been set at 430 days, allowing time for the group to be transferred back to the orbital ships for the return trip.

Although the voyage from the surface to the satellite orbit requires the expenditure of much fuel, to attain the proper velocity, the return to the surface may be accomplished rather economically. With only a slight reduction in velocity, the ship will descend, and the effect of the atmospheric resistance will still further decrease its velocity until it has reached the surface to be landed in a conventional manner.

The above discussion has been based on the use of chemical fuels. Dr. von Braun, whose calculations formed the basis of the outline, is of the opinion that the use of muclear energy is in the future, and indeed that it may be restricted to the use of the orbital ships, since radiation-contamination of the launching sites would be dangerous and inhibit their continued use.[22] Another

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22. Wernher von Braun, "The Importance of Satellite Vehicles in Interplanetary Flight,"

handicap would be the shielding required to protect the crew from the radiation. Dr. Lyman Spitzer has designed a ship for orbital travel powered by nuclear energy utilizing an accelerated ion beam to achieve the requisite velocities.[23]

23. Lyman Spitzer, Jr., "Interplanetary Travel between Satellite Orbits," Journ. Brit. Int. Soc., November, 1951.

Part of the work of the expedition will have been accomplished prior to setting out from Earth. Before entrusting human life on a journey of this extent, unmanned rockets will have been sent on similar jaunts, entering into orbit above Mars, and then returning. While circling above the planet, reconnaissance of the surface could be made by camera, and maps could then be prepared for use by the members of the group. The thinness and clarity of the atmosphere should permit excellent observation.

During the period of waiting, while the orbital ship is circling above Mars, it will serve several functions to relieve the base on the surface of some phases of its work. Primarily its job will be as a communication center, relaying messages and data from the base to Earth and return. By this means, the equipment required on the surface can be considerably reduced, and more continuous reception is assured. A secondary function will be to serve as an adjunct to the meteorological unit, for upper-air observations. A simplification of the supply problem is also obtained from the orbit. The automatic weather stations would be released from here, as would the equipment for the advance base. Expendable supplies could be stored up here if needed in great quantity and dropped as the need arose, using small guided "missiles" to transport the material.

Organization of the Center

The organization of the surface section of the expedition reflects the primary types of data required for subsequent operations. The personnel and composition of the remainder of the expedition, that remains in the satellite orbit, is not dealt with here, since it does not require shelter on the planet. The following is a tentative suggestion of the men required for the several purposes, as determined from interviews with men in these fields. The infinite details of organizing and carrying out plans for an expedition of this nature would occupy a considerable period of time. This listing merely serves to indicate the type of personnel needed, and the functions to be housed in the base. Any person entrusted with the responsibility for conducting such an operation would undoubtedly devise a different pattern, though the over-all concept should be similar.

ADMINISTRATION:	Director	1
	Yeoman	2
	Supply Officer	*
SCIENTIFIC OPERATIONS:	Meteorologists	3
	Technicians	6
	Biologists	3
	Doctor	1
	Technicians	3
	Geologists	4
	Technicians	4
TECHNICAL SERVICES:	Radiomen	2
	Pilot-mechanics	2
	Machinists	1
	Cook	1
TOTAL		33

The administration of the entire operation is the responsibility of the director. From the inception of the project, he will have been intimately concerned with its make-up. The selection of the proper personnel will be one of his most vital concerns. Far more so than similar groups on Earth, these thirty-three men will share their lives with each other exclusively for a longer period of time under conditions of extreme uncertainty. For this reason, the choice of men is dependent not only upon suitable technical qualifications, but also upon having a personality and character well adapted for such life. Although the director must necessarily base his decisions on a personal assessment, techniques now being developed by psychologists will assist him in selecting men not only technically qualified but capable of adjusting to the interaction of the personalities of the group-members.[24] A small group such as this is absolutely dependent on harmony between its members as well as identification of individual purposes with that of the group. Because of the isolated nature of the operation, it is necessary that each member be able to act as leader, should the need arise. For this reason, it may be advisable that the director appoint his second-in-command after the group has been formed and some selection has occurred.

24. Fillmore Sanford, in "Groups Leadership and Men," p. 176.

A supply officer is necessary for administration; however, he would be chosen from the personnel, and would be assigned this as an additional task. Since the number of personnel is limited, it will be necessary that every member be qualified in some minor capacity as well, and several jobs will have to be adopted as a common duty. Labor of erecting the Center is a typical example.

As in many groups, there are many administrative details to be handled in the field, and it is also advisable that as much of the technical reporting be done on location as possible, not only to enable a final report soon after completion of the mission, but also to serve as a check on the completeness of the various surveys. Two yeomen are assigned to assist the director and others in the accomplishment of this detail.

Program to be Carried Out

Geology

A major consideration with reference to the future development of Mars will be based on its supply of raw materials. It is doubtful whether shipping raw materials from Mars could compete with Earthside supply in the reasonable future; there is a possibility that fuel supplies for space travel might, however, be obtained there, reducing the necessity for lifting the fuel against the graviational force of the Earth. The findings of the geology section will serve this purpose, as well as helping to understand the past development of Mars.

Four teams of geologist-technicians could be formed. Usually, two would be operating in the main center, while two would form part of the group at the sub-bases. The personnel at the sub-base would be changed constantly to enable all members to become familiar with field conditions. Work in the field would be based on studies of the maps prepared from photographs taken by the unmanned rocket. Locations for further study could thus be chosen and easily surveyed. The nature of the field work to be done would depend greatly on the nature of the terrain, but the following phases of investigation seem indicated. Primary study would be of course of the rock types found, their mode and distribution, coupled with a survey of the topography and relief. Samples would be taken in the field for further study at the base. Laboratory analysis of the samples would utilize both microscopic examination of thin slices, as well as rudimentary geochemical analysis and assay. If suitable means of transportation are available, use of diamond drills to obtain cores would be of inestimable value. Although complete notes will be taken in the field, the collating of the data in the form of maps and papers will be done at the base.

Geophysical methods of measuring certain physical properties of the subsurface material are a prime necessity, even though some data can be obtained from interpretation of the surficial observations. The properties checked on Earth, and probably of value on Mars, are the density, elasticity, conductivity, and magnetic response of the formations under the survey point. The method chosen depends on several factors. Gravimetric and seismic surveys are the most reliable, but require extensive ground work, while the use of the magnetometer permits faster coverage of a large territory with generally adequate accuracy. If satisfactory performance of aircraft can be assumed, extensive areas could be covered rapidly by this means.

Meteorology

Meteorological investigations would furnish much data for use in advancing our knowledge of the forces influencing our own weather, and naturally would aid in locating future settlements on Mars, should they be found desirable. The personnel here, besides the three meteorologists, are instrument technicians as well as observers, since much of the equipment is electronic. The many phases of investigation desirable here would indeed be impossible for a crew of this size were it not for this type of equipment. Due to the vast expanse of territory to be covered continuously throughout the stay to obtain even a semblance of pattern, the use of much automatic equipment is necessary, and much of the data will be transmitted to Earth for correlation and analysis. However, since communication with Earth may be interrupted during the period when Mars and Earth are on opposite sides of the Sun, it will be necessary for the teams to make analyses at the base. This is also desirable, to show the trends of the investigation, as well as the detection of local conditions that might affect the base.

All of the standard observations (temperature, barometric pressure and pressure tendency, relative humidity, precipitation if any, wind speed and direction, and quantity of light from the sky) are obtained from automatic weather stations.[25] These have been developed for use in polar, oceanic, and other remote locations to complete the world weather network, and are generally designed to operate unattended for periods of six months.[26] The placement of these units, forty-six in all, would be from the satellite orbits, using the same basic technique currently employed from aircraft. Upon reaching the surface, anchors are released, and relays set the unit into operation. Coupled with each unit would be a captive-balloon apparatus, to raise sensing devices through the first hundred feet, thus furnishing microclimatological data in addition to surface readings. A wire sonde unit relays the information to the ground unit, where it is combined with the data from the surface elements, and transmitted by radio to the telemeter receiving apparatus at the main base, thence through the teletypewriter channels to the ships in the satellite orbit for relay to Earth. To obtain data

25. Michael Ference, "Instruments and Techniques for Meteorological Measurements," p. 1217.
26. Hq., Air Weather Service, "Automatic Weather Stations," Air University Quarterly Review, Winter, 1951-52.

unaffected by the interference of buildings, even the instruments at the base are remote-indicating, being located 500 feet from the building, and connected to the telemeter registers by wire. The remainder of the forty-six units are spaced equally along the meridian on which the base is located and the equator.

Information is obtained on upper-air winds by tracking by radar a balloon bearing a radar beacon, containing also sensing elements. This data is likewise integrated into the telemeter registers, using the radar impulses as channels,[27] while the observer at the radar console plots the course of the balloon. Besides this use of radar, the equipment would enable observation of cloud formations, determining development tendencies as well as cloud-base and -top.

Of great concern for life on Mars is the amount of radiation reaching the surface, and this too will be checked, both from the surface and from the satellite. Studies at the base and sub-base will determine the amounts and type received, as well as the effects on the circulation. In conjunction with the geologists, they will study soil temperatures and soil hydration

27. Ference, op. cit., p. 1213.

for aid in microclimatological studies. Part of the work of the section will also tie in the biology section in the field of aerobiology, the distribution of living organisms by functions of the atmosphere. Although it is likely the concentration is considerably less than in the Erath's atmosphere, certain forms may find it possible to exist under conditions found aloft. These studies would be carried out through the use of the balloons, so that the environmental data could be correlated with the results.

Biology

The distribution of life forms by the atmosphere would be but one phase of the over-all pattern of distribution, of great interest to the biologists. Closely connected with this is the investigation of the means by which life exists under the prevailing conditions. For this purpose, in the laboratory is provided a duo-culture incubator, allowing duplication of the external environment together with a contrasting terrestrial atmosphere for control. Through this means, the effects of the indigenous life forms on, first, the personnel at the base, and secondly, on Earth when this group returns, may be checked. The major field of interest of the physician for the expedition, who has been assigned to the biology section, will in fact be the effect of living on Mars upon the personnel. This is of course beyond his responsibility for the maintenance of health of the group. He would conduct physiological examinations of all personnel at frequent intervals, not only to prevent any danger resulting from contagion or infection, but also to continue the studies of the effects of travel in space and habitation away from the Earth, which by then would have been initiated at the satellite about the Earth. Coupled with this, for the ease of determining effects of life there, are studies using animals, in all likelihood the familiar laboratory rat, under conditions and exposures of potential danger to men.

A further responsibility of the biology section is the frequent inspection of the mechanisms providing the synthetic environment within the base. Checks on the purity of the water and the atmosphere within are essential, to prevent the concentration of toxic materials in either. This is most vital since both are recirculating systems operating within a closed circuit.

Photography

One of the accessories required for most of the work on

Mars is a camera. The geologists will use it to record the conditions of the area where samples are obtained, along with studies of the topographic expression, vital to the correct later summary of the field work. The meteorologists will find it useful in the recording of the indications on the radar scope, for future detailed study impossible under the restless shifting of the image. Biologists could record the conditions under which life forms are found existing. The effect of Mars on photography is quite apt to be surprising. Exterior shots might well suggest unusual exposure conditions.

The possibility that the contrast effects might be too great for the latitude of the film to record might lead to the necessity for dual exposures of all external scenes, especially in color film: one for detail in the highlights, the other for detail in the shadows blacked out in the previous exposure. The use of high-intensity flash may be sufficient to balance the light, at least for short-range exposures, just as in synchro-sunlight techniques on Earth. Due to some of the difficulties encountered by men in extremely cold regions, some changes in procedure may be required.

Equipment used may be divided into two groups: the first being conventional equipment protected against the environment, offering at the present a greater flexibility than that of the second group. The first type would be used at the base, where conditions are similar to Earth. The second type would be a development of the Polaroid Land camera.[28] The development would be a separation of the exposing and developing phases, which at present are combined. This separation would also permit a more rapid sequence of shots, uninterrupted by the necessity for developing one exposure before taking the second. The main reason for the separation of the phases is that the temperatures may at times be too frigid for the proper action of the chemicals. This in all likelihood would be the type provided for the sub-base; however, ease of duplication and magnification may still favor normal equipment at the base, where extreme conditions do not prevail. The water required for processing would be separate from the normal system. It neither requires the same purification processes nor would the possibility of contamination from the occasionally poisonous chemicals be completely absent. Since the quantities needed are not great, the equipment required for this can be simple and compact.

28. Suggested in a conversation with the writer by Dr. A. C. Hardy.

Structure

The problem of housing a Center of this nature involves several considerations not common in building under normal circumstances. Besides the shelter functions, the structure must be easily transportable, easily and quickly erected, and preferably one in which the inner surfaces have no contact with the unfamiliar environment.

The primary function of any building is to shelter the activity contained within itself: enclosing, supporting and protecting the synthetic environment within.[29] Through the ages, the degree of separation of the two functions of support and protection has varied, from the complete mersion typified by the load-bearing masonry wall of the Maya to the differentiation typified by the frame (branches) and skin (reed mats, or hides) structures of the North American Indians. Most modern structures are more akin to the latter approach, though in many cases, the skin is utilized for subsidiary support (bracing the main frame).

A prime consideration on Earth is the factor of weight: the loading on the structure, including the loads supported as well as the weight of the structure itself.

29. James Marston Fitch, "American Building," p. 165.

Other forces are effective at times, resulting from the impact of wind, or from earth tremors. Transferring these loads to the ground generally requires rigid connections or fottings at a multiplicity of points. The result effectually transmutes the synthetic structure into being a part of the natural surface. The work necessary for this type of contact usually involves substantial labor at the site, utilizing both machines and men.

From the description of Mars, it becomes apparent that two factors effect a major change in structural analysis: the lessened gravity, and the difference in pressure between the Martian atmosphere and the normal atmosphere on Earth, which must be provided within the shell. Normal pressure is approximately 14.7 psi; while men may become acclimatised to lesser pressures, the effects on their efficiency are not certain. Pressure at the surface of Mars is approximately 1.2 psi, giving a differential of 13.5 psi, or 1950 psf. Resisting the force thus developed becomes an insuperable task if attempted in a framing system. The members required would be possible on Earth: the exigencies of supply and erection on a Martian location removes any practicality. The possibility of using this pressure for support rather than resisting it suggests itself as one solution.

Most pressure-vessels on Earth are constructed of sheet steel, in small panels welded or riveted together. Considerable equipment and time are required for the fabrication. Similar techniques on Mars are obviously out of the question: beyond the specialized equipment needed, skills of little other value to the expedition are demanded and the time is longer than desirable. Other objections to the use of metal would seem to be the weight required, and the question of means of providing vision.

Several projects on Earth have resulted from the application of the principle of using internal atmospheric pressure for support. H. C. Stevens has proposed several; one, an arena, utilized a slightly higher pressure of 20 psf to support a light-weight skin as a roof. An air lock was required to maintain the internal pressure during the entrance and exit of its visitors. In 1934, John MacMillan in Minneapolis designed and built a 70,000-cubic-foot grain storage building, using a pressure of 70 psf to form and erect the cylindrical roof of 22 gauge sheet steel.[30] This unit was

30. Joseph A. Wise, "Roof Supported by Air Pressure," Engineering News Record, 30 Nov., 1944.

subsequently dismantled, not for structural failure, but because of danger of explosion from the grain dust suspended in the air. Rubberized balloons have been used successfully as forms for pneumatically applied cement by Wallace Neff in several projects, mainly residential. However, one large market has been roofed with a dome built under his design.

Thus the use of internal pressure as a structural element is feasible. An examination of the manner in which it can be applied in conjunction with the other desirable characteristics of a building to be transported to Mars leads to the following considerations. Beyond demanding a material strong enough in itself to resist this pressure-loading, any joints must likewise resist the tension developed, and the weight and bulk of the unit itself, as well as any erecting equipment necessary, must be kept to a minimum.

The first approach suggesting itself is the use of a hemispherical dome within which the activities could be carried on. However, to reduce the equipment carried to a minimum, it seems desirable to avoid having to prepare a level compacted site. A small platform elevated slightly above the surface by short columns adjustable in height would seem to serve the purpose, until the pressure is taken into consideration. Any surface in extensive contact with the shell containing the pressure will be subject to a loading equivalent to 1950 psf. This by comparison with the normal loads is quite high, and would require heavy members.

By analogy with the storage of water in which comparable loading may be developed, elevating the shell to allow the formation of a complete spheroidal shape utilizes the material to its fullest degree, and removes the problem of the transfer of pressures, since the shell is now essentially a self-contained system. The few supports required for the elevation of the spheroid are merely needed to transfer the weight of the shell and its contents to the ground. Here the second factor of importance on Mars enters: the lessened gravity. The weight of any object on Earth will be reduced by a factor of 0.38 when on Mars. This allows the columns to carry a much greater effective load.

A material possessing a much higher strength-weight ratio than steel is found in fiberglas-reinforced polyester plastic.[31] Gaining its strength in a manner similar to concrete reinforced with steel rods, its physical properties are superior to steel in several respects. The strength-weight ratio is higher,

31. Richard J. Francis, "Reinforced Plastics," Product Engineering, February, 1951.

corrosion and abrasion resistance is high, and it can be obtained in a flexible, easily stowable form. By choice of the proper resin, it is possible to determine the degree of flexibility of the resulting sheet. To obtain the highest strength characteristics, the fiberglas reinforcing can be obtained in fabric-weaves. Of importance on Mars because of the low temperatures, is the fact that most properties are improved by a decrease in temperature.

The choice of a resin possessing an index of refraction similar to glass permits panels to be made transparent. Certain research along these lines has been done by General Electric Corporation, Wright Field Development Center, and one commercial producer is marketing Duralux, a transparent reinforced sheet transmitting up to 90% of the visible light transmitted through air. Incorporated into the material will be chemical fillers to filter UV radiation, reduce the intensity within the Center as well as preserve the material itself. The shell will be made of three layers, divided by an unplasticized strip of fiberglas fabric, porous to allow the supporting air pressure to reach all points, yet dividing the layers into smaller panels to reduce convective motion. The inner and outer layers will be transparent, while the middle layer, over the greater portion of the shell, will be metallized: an aluminum coating on the inner surface to reflect heat back into the interior, a black surface on the exterior to absorb heat radiation from the Sun.

The approximate tension on the outer skin can be calculated from the formula: $f = pr/2t$,[32] in which f is the unit-stress developed; p, the pressure per unit area, has a value of 13.5 psi; r, the radius of the sphere, 192 inches; and t, the thickness of the layer, is 0.065 inches. The resulting value for f of 20,000 psi is within the allowable tension of fiberglas reinforced plastic, set at 47,800 psi for fiberglas cloth no. 143, a unidirectional weave laid in cross-laminate.[33]

The shell is supported at three points, the packaging point and two exterior struts. At the point of junction for the two struts, an additional layer of satin-weave fabric is added to distribute the pressure-loading, similar to the use of a steel grid above the column in Smooth Ceiling reinforced concrete. The sockets for the struts are incorporated into the shell at the time of

32. Swain, George F., "Structural Engineering--Strength of Materials," p. 463.
33. Owens-Corning Fiberglas Corporation, "Reinforcing Cloths," Fiberglas Standards PR6.A1.

fabrication to provide for the slight variation in thermal coefficients of contraction, although fiberglas laminates have coefficients about equal to those of metal, in the range of the aluminum alloys.[34]

Total load on the two floors within each shell is estimated at 54000 pounds; the weight of the shell approximately 2000 pounds; the floor-structures at 500 pounds; and the volume of air inside at 1300 pounds; giving a total of 57800 pounds. However, the lower gravity of 0.38 g on Mars modifies this to be an effective 19270 pounds, to be distributed over the three points of support. Carrying only 7000 pounds, these struts are governed by the need for stiffness and rigidity over their length, so that tubular sections seem the best. The third point of support is at the joining of the shell to the portion of the landing craft devoted to transporting the Center. To avoid joints which would weaken the structure and offer the possibility of leakage, the flexible shell is merged into the inner shell of the landing craft, by a shift in the resin during fabrication to give rigidity to the craft. The use of the plastic for the ship is logical, since it too must resist the same internal pressure. Here the plastic

34. H. C. Engel, et al., "Structural Plastics," p. 99.

shell would be covered with materials suitable to resist the skin temperatures developed during the flight down from the orbital ships, and one of the covering layers could serve as a meteor bumper[35], to explode meteors before they penetrate into the interior, during the flight from Earth to Mars. The continuity possible in the transition from rigid to flexible plastic shell eliminates any seams and makes possible a higher level of structural efficiency.

The two floors in each shell are supported on cables running from grommets integrated with the outer layer of the shell, passing through gaskets in the two inner skins. A band of reinforcing fiberglas at this level transfersthe floor loads to the shell, to be resisted by the outward pressure of the atmosphere. Here, too, the gravity factor effectuates each floor load at 9000 pounds. The second floor is made of two rigid reinforced plastic sheets separated by a hollow core to allow air to be distributed for heating and ventilation, and also acts as a radiant panel.

35. Fred L. Whipple, "Meteoritic Phenomena and Meteorites," p. 52.

The Internal Environment

Since the environment on Mars is unsuitable for unprotected human life, it is necessary for the base to be able to provide a synthetic environment within the shell, to enable the personnel to live without the necessity of wearing pressurized suits. Naturally, when they leave the shelter of the base, they must don them, but their activities should be so coordinated that such trips will be reduced to a minimum.

Food Storage

The factors governing the mechanical facilities to be provided are related directly to the mechanism by which the body develops its own energy. The total energy output is the resultant of two factors: one, the energy needed to maintain body temperature and functions, the other varies with activity and food consumption.[36] The over-all food consumption can be estimated on the basis of the activity expected. There is a possibility that, due to the lessened gravity, the energy needs will not be so high; countering this are the lower temperatures prevailing, and the unfamiliar conditions. For this reason, I adopted the requirements for a moderately

36. Benjamin Harrow, "Textbook of Biochemistry," p.435

active man, 3000 calories per day. This requirement can be satisfied with about 19 ounces in a balance of protein, carbohydrate, and fat, in a highly concentrated form.[37] However, to obtain a greater variety of foods, I have used an allowance of two pounds per day per man.

The space required for the storage of this food is dependent upon the means of preservation used. Dehydration, removing 75-95% of the water within the foods, greatly reduces both the weight and volume required. For this reason, it seems practical to assume that the majority of the foods will be so treated. After this processing, the foods will be packaged in film, and hermetically sealed within a metal pack under vacuum. Providing the two pounds per day per man leads to a total of 28,830 pounds. Based on an average of 36 pounds per cubic foot, the space needed is 788 cubic feet.

Preparation of this food is relatively simple, requiring only the addition of the water removed to restore the food to an edible condition. Normal cooking procedures are then followed. To simplify the cook's tasks, the menu for each meal will be separately boxed, so that only the proper packages need be opened in the preparation of a meal.

37. Paul A. Siple, op. cit., p. 356.

Another necessary element enters here, however, To obtain this energy of 3000 calories, the food materials must be oxidized. Since for every liter consumed, approximately 4.8 calories are produced,[38] the amount of oxygen required is 625 liters per day per man, or 20625 liters per day. For the period spent on Mars, a total of 15.0 tons is required. Storage of this amount can be handled in several ways. Liquefaction, with a two-to-one advantage over gaseous oxygen in weight, involves difficult storage problems, and through evaporation (occurring at all temperatures above -183°C.) loses a considerable volume. Best available methods today are limited to 1% per day.[39] Thus it is evident that liquefaction does not solve the problem of storage for 430 days. Pressures of 1500 psi have been used some time for this purpose, and seem a more practical solution. However, because of the volume required for this type of storage, supplies of oxygen would be dropped as required from the orbital ships.

Other means of providing oxygen are available. Use of plants is frequently advocated. Catalpa leaves could be used, if an area of 321 square feet per man were

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38. Harrow, op. cit., p. 436.
39. Professor Samuel C. Collins, in a discussion with the writer, 9 May 1952.

available, or a total of 11,000 square feet. Better efficiency has been estimated for algae by Dr. Heinz Specht,[40] with a requirement of only 11 square feet per man, or a total of 363 square feet. However, efficiency as obtained in the laboratories of Arthur D. Little, Inc.[41] is of a much lower order, and the area required is similar. Beyond the mere provision of this area, the questions of water and nutrient supply, and the equipment required for the installation seem to negate the advantages at present. Similar restrictions seem to apply to the provision of the food supply.

Another means is by the addition of water to sodium peroxide crystals.[42] As the peroxide dissociates, oxygen is liberated, sodium hydroxide is formed which absorbs the carbon dioxide from the air and other impurities, and a certain amount of heat is evolved. The presence of caustic alkalies in the system is dangerous, particularly in view of the extended period under which the system is in operation. From the oxidation of the food, certain waste materials are produced. Carbon dioxide and water are the major items. Carbon dioxide

40. Heinz Specht, "Toxicology of Travel in the Aeropause," p. 14.
41. Dr. . Fisher, in a discussion with the writer, 23 April, 1952.
42. H. G. Armstrong, "Principles and Practice of Aviation Medicine," p. 312.

is liberated to the extent of 85% of the oxygen consumed; 4.3% of the exhaled breath is carbon dioxide, though the standard concentration in the air we breathe is only 0.003% and this excess must be removed. A 30% solution of sodium hydroxide will absorb about 1 kilogram of carbon dioxide per two liters; for the entire period, 820 cubic feet will be required if stored in solution.

Water and Sanitation

Coupled with the daily requirement for food is one for water: as a solvent, a carrier of food to and waste from the tissues, and as a regulator of body temperature. The normal requirements are approximately 3000 cc per day per man, or slightly less than one gallon. Supplying this quantity direct would involve an enormous volume, but is quite unnecessary, fortunately. The water required by the body is liberated again in several forms,vaporization from skin and lungs, and in sewage. The water emitted into the atmosphere, somewhat over half the total produced, may be recovered in the ventilating system, purified and returned to the water supply. The water in the sewage can be recovered through the use of a system proposed by Harold Horowitz.[43]

43. Harold Horowitz, "Autonomous Facilities for Deployment Housing," p. 19.

Sewage is received by a solution of ethylenediamine, which dissolves and sterilizes the waste. Distillation then separates the ethylenediamine and water, leaving a sterile residue to be removed. This water, now purified, can also return to the water supply, although the factor of the possible presence even in the distilled water of other impurities demands constant checking by the biology section, and would favor reserving a tank of fresh water to add to the regular supply at intervals. Since almost the total daily requirement can be recovered, only three months' supply is provided, to allow for the necessary replacement. Water used in the various laboratories is a separate system.

Allied with the matter of internal requirements is the use of water for cleanliness. Since the system is closed, it would be possible to have normal facilities, but baths would demand a system of greater operating capacity. A chamber for showers is included instead, utilizing the emission of a mist and detergent for cleaning, on the principle of a steam bath, as recommended by Siple. The detergent would form a part of the solid residue, which would be expelled mechanically through the side of the central cylinder, to eliminate the possible contamination by dust in the internal atmosphere.

Ventilating

Circulation of the internal air presents another source of possible contamination from toxic factors caused by metabolic activities.[44] Certain volatile compounds are produced during the oxidation of food products. Together with such contaminants may be bacteria and other biologic forms. Beyond these sources of potential danger lies the annoyance of odors, resulting from the several activities as well as from the functions of the body. For the control of these elements, absorption will suffice for some, though electrostatic precipitation will remove a major portion of the particles. All of the air in the system is passed through this stage as well as ultraviolet radiation, to prevent the spread of disease. In general, the elimination of odors will serve as a criterion of the effectiveness of air circulation in a closed system, and calls for a rate of about 30 fpm as a desirable norm.[45]

Closely associated with the rate of change is the relative humidity and temperature. For the inside temperature selected below, the relative humidity should be about 20%, both for comfort and health. The dehumidifier in the system serves to maintain this level,

44. Specht, op. cit., p. 3.
45. Ross A. McFarland, "Human Factors in Air Transport Design," p. 157.

returning the excess water to the purification system for use in the water supply.

Heating

From the description of the temperatures prevailing on Mars, it will be seen that while the daytime level may be suitable, the level reached at night may be as low as -20°F. normally on the latitude chosen. A minimum inside temperature of 60°F. with a relative humidity of 20% is obtained on the comfort chart prepared by the ASHVE, though this is slightly below the normal level for American houses. Normal acclimatisation functions of the body will enable the difference to be absorbed.

Thus during the night there would be an 80° difference between external and internal conditions. Since during the day, temperatures are satisfactory, a design temperature of -15°F. was adopted, resulting in a change of 75° for the daily average. The central cylinder is insulated, having a value of 0.12 Btu./hr./°F. change in temperature. The opaque portion of the shells, having a reflective film in the center, has a calculated value of 0.09, while the greatest loss is through the transparent portion. During the day the value here would be 0.28, reduced by the value of the insolation received through it, while during the night to reduce the loss, a drapery woven of milium reflective material would be drawn around inside the dome. Recent researches at Purdue University have demonstrated the substantial value of such material.[46] Calculations of the total heat loss based on these values modified for the insolation-milium effects, indicate a total heat loss of 110,000 Btu./hour.

In the absence of substantial quantities of oxygen, it is not feasible to consider the use of combustion of fuel for heating. The sources left depend on electric radiation and the use of solar energy. Since 1 kilowatt is the equivalent of 3400 Btu/hour, 35 kw would be required to balance the system, if a panel similar to USKON as developed by the United States Rubber Company were used. A later discussion on power supply will demonstrate the impracticality of this method.

As noted in the description of Mars, the planet is able to absorb solar radiation to a level of 61% of that absorbed by the Earth. Dr. Abbot has calculated that the average solar radiation constant on the Earth's surface is 1.35 cal./min.cm.^{2},[47] a value equivalent to

46. Clarence A. Mills, "A Year's Operating Results for Reflective Radiant Conditioning," p. 75.
47. Charles G. Abbot, "Solar Radiation as a Power Source," p. 100.

300.9 Btu./hr./ft.^{2}. Sixty-one per cent of that value is 183.6 Btu./hr./ft.^{2}, which I have assumed for the value at the surface of Mars. In a discussion on solar heating, Dr. Maria Telkes cites an efficiency factor of 37%[48] for the multipaned flat-plate collectors used in her designs. Since transporting glass and erecting a multiplicity of panels on Mars is not too convenient, a system similar to that used for the structure of the shell has been adapted to replace the glass element. A ring 16 feet wide, built of 6-inch plastic ducts, is supported within a multishelled plastic envelope, using air pressure for rigidity. The unit is supported eight feet above the surface by a series of light struts, to allow passage to the Center. The under surfaces of the ducts and the envelope are aluminized, while the upper surface of the ducts is black to absorb heat radiation. Raising the ring above the surface also reduces the heat loss to the ground.

A ring of the dimensions shown, operating at only 25% efficiency, will supply 342,000 Btu./hr. Since the atmosphere of Mars is relatively clear and clouds, though present, are not serious, only a slight override seems adequate for storage. Although water may be used,

48. Maria Telkes, "Solar House Heating," Heating and Ventilating, May, 1947, p. 75.

Dr. Telkes indicates that Glaubers salt is seven times as effective for heat storage. As one pound of salt will store 104 pounds, a total of 33,000 pounds are required for storage, with a volume requirement of 370 cubic feet. Air is circulated through the ducts, absorbing heat from the blackened surface, and enters the cylinder. The heat is there transferred to the containers of salt, and the air recirculated through the ducts. At night this recirculation is eliminated, blocking that heat loss. As heat is required in the Center, air is passed over the containers, absorbing heat and then circulated through the hollow-core second floor, emerging into both floors, and withdrawn through the entrance to the cylinder. There it is collected and returned to the ventilating equipment for purification.

Lighting

General illumination of the units will be handled by panels utilizing electroluminescence as their source. Developed to a fair degree by Sylvania engineers,[49] the effect depends on the excitation of certain phosphors in a fluctuating electric field, apparently a direct transformation of electric energy into light. Over a

49. E. C. Payne, et al., "Electroluminescence," Illuminating Engineer, November, 1950, p. 688.

transparent conducting sheet is deposited a thin dielectric layer containing the phosphors. Another conducting layer with a reflective backing is then placed on top, and connections are made. Panels with 20 footlamberts have thus far been obtained. Since this panel could be incorporated into the construction, the savings in bulk are obvious.

Communication

Communication between the base and Earth is by relay through the orbital ships. J. J. Coupling, an electrical engineer, has calculated that using teletype, the power required to communicate with the Moon is only 10 watts, using a wave length of 3 cm.[50] Since the satellite orbit is only 620 miles above the surface of Mars, the power should be less. Teletype is preferred to voice for the long-range contact with Earth because of the power factor (1000 for voice) and because the teletype, used in duplex, allows continuous operation, save for the period when interference by the Sun blankets all communication. Voice is also impractical since the distance requires an average wait of 6.2 minutes between question and answer. However, between the Center and the orbital ships, and personnel away from the Center, voice is quite practical.

50. J. J. Coupling, "Don't Write, Telegraph," Astounding Science-Fiction, March, 1952, p. 92.

Power

One of the major considerations in the project is the power supply. Upon this depends the operation of virtually all other functions. Due to the lack of oxygen, combustion is an unlikely source, even were a fuel supply likely to be found. Due to the lack of water vapor, and lack of visible sources of water, this possibility is also eliminated. There remain several other possibilities.

Nuclear energy was discussed in the section on interplanetary flight. There remain a great many problems to be solved both in the release of energy from a pile and in the means of utilizing the emissions in the generation of power. The promise is not bright; the potential is limitless. An unlimited source as this would remove the necessity for several of the functions found necessary: the ring for solar heating could be eliminated, for example.

Solar energy is another possibility. Here again a great many problems remain to be solved. Efficiencies of about 1% are obtained from flat-plate collectors, though parabolic concentrating elements are given a calculated efficiency of 15%.[51] On a theoretical basis,

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51. Eugene Ayres, "Energy Sources," p. 193.

adapting Dr. Abbot's calculations, an area of 540 square feet (a unit 26 feet in diameter) would be required to supply even 5 kw. Since this would only operate in the daytime, and energy would have to be stored, the units involved become immense. Other means of tapping the Sun's energy remain, however. Rabinowitch has developed a cell based on the effect of radiation on the equilibrium between two elements of iron and thionine, one exposed to light, the other shielded, achieving an efficiency of 0.5%. With a similar use of thermocouples, Dr. Telkes has obtained an efficiency of 7% under laboratory conditions.[52]

One source yet remains for consideration. The meteorological studies indicated that winds of about 10-20 miles per hour were present on Mars. As this is the range in which wind-generators are effective, reaching an average rated power of 2 kw per unit at 20 mph,[53] it seems feasible to install several units about the Center, storing the energy in batteries until needed.

Transportation

Power for mobile transport on the surface is subject to the same restrictions as above. One solution might be

52. Ayres, op. cit., p. 201.
53. Ibid, p. 256.

in the use of concentrated hydrogen peroxide and fuel oil.[54] The heat of dissociation of H_2O_2 into H_2O and O ignites the fuel oil injected into a firing chamber and the water is converted to steam. After driving a turbine, the vapor is condensed, CO_2 and CO released, and water returned to the system for reuse. This unit may provide power for several small tracked tractive units, as well as the aircraft needed for transportation between the Center and the sub-bases. There is little doubt that aircraft could function in the Martian atmosphere.[55] The low lifting power of the air is only partially countered by the low gravity, so that wings of four times the area required on Earth would be needed. Flight would usually be near the surface as well.

54. Wernher von Braun, "Mars Project," p. 336.
55. Arthur C. Clarke, "The Exploration of Space," p. 144.

SOUTH

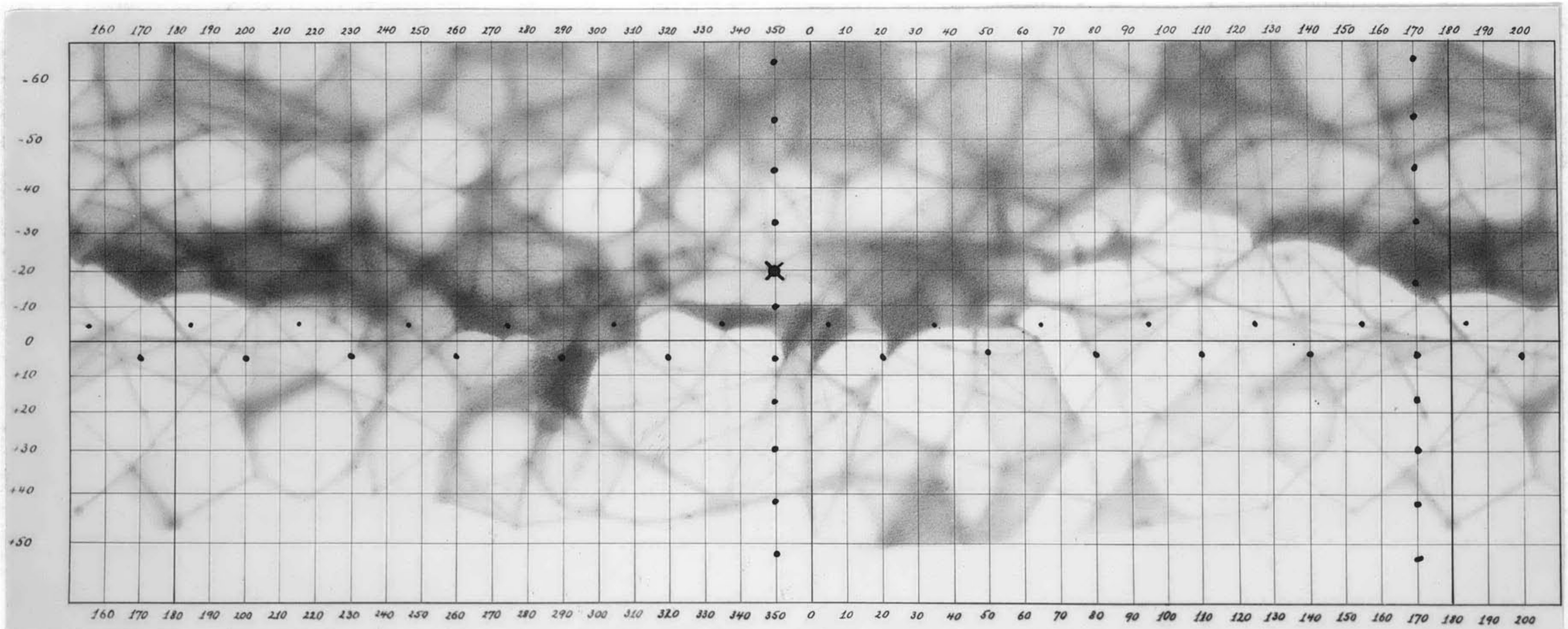

CHART OF MARS SHOWING LOCATION

Layout and Erection

Combining the foregoing elements into a unit has resulted in the design of the Center as shown in the drawings.

The location of the Center was based on the temperature and wind charts (Figures II - IV); the site selected, 20°S, 350°W, has a warm temperature and its position near a low should provide a steady wind for power. Located within a desert region, the rock will serve as a foundation, and the possibility of moisture-seeking plant life infesting the surfaces should be reduced.

Entrance to the Center is through the airlock located under the junction of the heating ring with the cylinder. The airlock permits the maintenance of the internal pressure and serves as a decontaminating chamber should protection against exotic forms of life be found necessary. Upon entering, the Martian atmosphere is first expelled, and replaced with a sterilizing mist. This too is withdrawn, and the normal atmosphere is admitted. Within the inner door is space for storing the pressurized suits and the mechanism for the airlock ventilation. Departure involves the removal of normal air, before the exterior hatch is opened, thus reducing the loss of air to a minimum. Vertical circulation from this area throughout the cylinder is by means of a ladder.

The second level provides space for the mechanical facilities: heat storage, ventilating equipment, water purification and storage. The third level contains the bath-laundry unit and food-storage, and provides entrance to the sleeping quarters, located on the lowest level of each shell. Placing them on this level allows the working areas to be above to use the light from the dome. Though the amount of space devoted to private purposes might be considered excessive, consideration of the period to be spent on Mars under highly unusual conditions makes it desirable to provide as much privacy as practicable. When men "are forced to live together for months at a time, without being able to get away or to talk to new personalities, they crave opportunities to be by themselves to read or study."[56] The beds are air mattresses, on panels supported by the metal framing of the partitions between cubicles. A chair, writing panel, and wardrobes are provided besides the two beds in each space.

The upper level in the cylinder contains shop equipment and materials storage. Due to the lack of complete

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56. Siple, op. cit., p. 330.

familiarity with the conditions there (which holds true for any area to which a group of this nature might be sent, else why go?), it would be impossible to prepare the proper equipment for all possible contingencies and developments. Almost all expeditions going into the field find it impossible to anticipate all potential needs.[57] For that reason, shops for the maintenance of equipment as well as the construction of new apparatus are found desirable, together with a stock of materials. Spare parts are carried for all parts likely to need replacement, but space and weight make undesirable a full complement of parts ad infinitum. Also located on this level are the photographic workroom, and the galley, adjacent to the entrance to the second floor of one of the shells. Equipment is provided for the rehydration of the food, as well as electric cooking facilities. The cook is enabled to prepare most dishes of a normal nature, to reduce the feeling of strangeness. Siple cites the importance, also, of an occasional delicacy.

The entrance nearby provides access to the common room, used for all dining purposes, and also as library, music room, auditorium, and gymnasium. The library provided is contained on microfilm; use of microfilm

57. Siple, op. cit., p. 289.

including provision of individual readers for each man, occupies only 25% of the volume required were books used. The 10,000 titles available provide for the three major purposes of men's reading: reference, study and recreation. Tape recordings are also available of a large selection of music, which may be listened to individually or played over the communications system. Also available are movies, both standard films as well as those filmed and processed at the base. Games of all sorts are also provided, and suitable sports equipment. "The wise leader should endeavor to see that the life of his men is as pleasant as possible if he wishes to keep harmony throughout this period."[58]

The second shell provides at this level the administrative area, with desks and equipment for the director and two yeomen. Closely connected with this function is the communication center. Posted in this area would be a transcript of news relayed from Earth. In the communications center are found the teletypes, transmitting and receiving apparatus both for relay to the orbital ships as well as for surface contact with the sub-bases and other personnel removed from the Center, and a test bench for use in testing and repair in both communications and meteorology sections. Since so much of the

58. Siples, op. cit., p. 330.

meteorology section's apparatus is electronic, it is logical to have a close relationship with the radio unit. Besides the racks for telemeter registers, a radar console is provided, together with analysis desks, plotting chart files, and storage cabinets.

The third shell contains the informary and laboratories for geology and biology. In the infirmary, facilities are available for both the examinations and any operations necessary. Dental and X-ray equipment is likewise supplied. To aid in the examinations, the biochemistry work-unit is adjacent to the infirmary, with the animal cages nearby for specimens. Another work u unit is provided for general biological and bacteriological work, near the duo-culture tanks and a constant-temperature chamber. The geological section contains an analysis bench for petrologic studies as well as geochemical assays. Desks and plotting tables for the preparation of reports are also included. Storage facilities are provided for specimens in both the geology and biology areas.

All of the equipment used above is stored in the cylinder during transit. Most of the equipment serves as packing crate for the contents to be used with it after erection.

Continuous tops are separate, placed over the assembly of base units. The choice of three shells rather than one for the Center was based on the factor of providing a secondary shelter in the event of damage to any of the shells. The sub-bases provide space for six men to live, and carry on field surveys. No laboratory equipment is supplied; benches for collating data and specimens, bunks, and mechanical equipment are the items supplied.

Erection of the Center is greatly expedited by the use of a portion of one of the landing craft. This section will be designed specifically for the task of transporting all of the equipment required within the Center, and then serving as the central section of the unit. Upon leaving the orbit ships, the rear portion of this vessel, containing the rocket motor and fuel to reduce velocity, will be jettisoned. Utilizing the atmospheric resistance for braking, the craft will descend to the surface. Upon arrival, the forward portion containing the control cabin will be removed, as will the deltaform wings, and small jato units attached to the intended upper end of the cylinder. Using cables to maintain stability, the cylinder will be raised from its horizontal position to a vertical axis by the jato units, Leveling is done by means of hydraulic jacks within the cylinder.

After positioning, a ring of ports just above the entrance hatch is opened, and the ring for heating expanded, with light struts for support fastened during the process. This must be done before the shells are expanded, since the struts supporting the shells would interfere with the passage of the ring. While this has been occurring, three ports are released to allow the shells to be expanded by the use of air under pressure in the cylinder. The air first enters the space between the three skins, then into the volume of the shell itself. As each slowly grows, two struts are fastened to it and then positioned on the ground using a cable jig. All struts are anchored to the ground by the use of cartridge guns setting pins into the surface.

Upon completion of these tasks, the group may enter through the lock, and proceed with the rearrangement of the interior. After fastening screw-fittings on the ends of cables to the grommet-unit protruding through gaskets from the exterior skin, a turnbuckle in the center establishes the proper tension in this cable-grid, upon which the floor panels can be attached.

After this the light metal framing is erected for the partitions, and the equipment is arranged in its proper location. Following attachment of the external oxygen chamber to the cylinder, the Center is suitable for habitation. Wind generators placed about the area will provide the necessary power, and communication is established on a regular basis with the positioning of the radar and radio antennae.

Similar procedures will be followed for the erection of the sub-bases.

Bibliography

Abbot, Charles G.: "Solar Radiation as a Power Source," incl. in Annual Report of the Smithsonian Institution, 1943

Adolph, E. F., et al.: "Physiology of Man in the Desert," Interscience, New York, 1947

Armstrong, H. G.: "Principles and Practice of Aviation Medicine," Williams and Wilkins, Baltimore, 1943

Ayres, Eugene, and Scarlott, C. A.: "Energy Sources--The Wealth of the World," McGraw-Hill, New York, 1952

Baldwin, Ralph B.: "The Face of the Moon," University of Chicago Press, 1949

Bolin, R. L.: "Utilization of Solar Energy for Power Generation," presented toward Master's Degree, MIT, August, 1950

Bates, Marston: "The Nature of Natural History," Scribners, New York, 1950

Buchsbaum, Ralph: "Readings in Ecology," University of Chicago Press, 1937

Buettner, Konrad: "Bioclimatology of Manned Rocket Flight," incl. in "Space Medicine," Marbarger

Buettner, Konrad: "Physical Aspects of Human Bio-climatology," incl. in Compendium of Meteorology, see Malone

Clarke, Arthur C.: "Interplanetary Flight," Temple Press, London, 1951

Clarke, Arthur C.: "The Exploration of Space," Temple Press, London, 1951

Coleman, H. C.: Editor, "Laboratory Design," Reinhold, New York, 1951

Coupling, J. J.: "Don't Write, Telegraph," article in Astounding Science Fiction, Street and Smith, New York, March, 1952

Cowan, Robert C.: "Flight Into Space," series of articles in Christian Science Monitor, 8 January 1952 ff., Boston

de Vaucouleurs, Gerard: "The Planet Mars," translated by Patric Moore, Faber & Faber, London, 1950

Ellis, Carleton, and Swaney, Milton: "Soilless Growth of Plants," Reinhold, 1938

Engel, H. C., et al.: "Structural Plastics," McGraw-Hill, New York, 1950

Ference, Michael: "Instruments and Techniques for Meteorological Measurements," incl. in Compendium of Meteorology, see Malone

Fitch, James M.: "American Building," Houghton Mifflin, Boston, 1948

Francis, Richard J.: "Reinforced Plastics," Product Engineering, February, 1951

Guetzkow, Harold: editor, "Groups Leadership and Men," Carnegie Institute Press, 1951

Haber, Heinz: "Flight At the Borders of Space," Scientific American, February, 1952, New York

Harrow, Benjamin: "Textbook of Biochemistry," 5th Ed., Saunders, Philadelphia, 1950

Henderson, Lawrence J.: "The Fitness of the Environment," Macmillan, New York, 1913

Hess, Seymour: "Some Aspects of the Meteorology of Mars," Journal of Meteorology, February, 1950, American Meteorological Society, Boston

Hess, Seymour, and Panofsky, H. A.: "The Atmospheres of the Other Planets," incl. in Compendium of Meteorology, see Malone

Horowitz, Harold: "Autonomous Facilities for Deployment Housing," special report to Department of Architecture MIT, January, 1951

Jacobs, Woodrow: "Aerobiology," incl. in Compendium of Meteorology, see Malone

Jones, H. Spencer: "Life on Other Worlds," Macmillan, New York, 1940

Ley, Willy: "Rockets, Missiles, and Space Travel," Viking, New York, 1951

Ley, Willy, and Bonestell, Chesley: "The Conquest of Space," Viking, New York, 1949

Lowell, Percival: "Mars as the Abode of Life," Macmillan, New York, 1907

McFarland, Ross A.: "Human Factors in Air Transport Design," McGraw-Hill, New York, 1946

McKinstry, H. E.: "Mining Geology," Prentice-Hall, New York, 1948

Maher, A. J.: "Building Shape vs Heating Efficiency," in Heating and Ventilating, The Industrial Press, New York, August, 1948

Malone, Thomas F.: editor, "Compendium of Meteorology," American Meteorology Society, Boston, 1951

Manchester, Harland; "The Astronauts are Serious," Harper's Magazine, Harper Brothers, New York, May, 1952

Marbarger, John P.: editor, "Space Medicine," University of Illinois Press, Urbana, 1951

Mills, Clarence A., "A Year's Operating Results for Reflective Radiant Conditioning," Meating Piping & Air Conditioning, Keaney Publishing Co., Chicago, February, 1952

Nason, H. C., et al.: "Low Temperature Behavior of Plastics," in Modern Plastics, Plastics Catalogue Corp., New York, December, 1951

Plastics Catalogue Corp.: "Modern Plastics Encyclopedia and Engineers Handbook," New York, 1951

Payne, E. C., et al.: "Electroluminescence--A New Method of Producing Light," in Illuminating Engineer, November, 1950

Rabinowski, Eugene: "World's Energy Supplies and Their Utilization," in Proceedings of American Academy of Arts and Sciences, July, 1951

Richardson, Robert S.: "New Paths to New Planets," in Air Trails and Science Frontiers, Street and Smith, New York, September, 1947

Siple, Paul A.: "Adaptations of the Explorer to the Climate of Antarctica," the dissertation submitted to Clark University in partial fulfillment of requirements toward degree of Doctor of Philosophy, August, 1939

Smart, W. M.: "The Origin of the Earth," Cambridge University Press, 1951

Specht, Heinz: "Toxicology of Travel in the Aeropause," paper delivered at Symposium on the Physics and Medicine of Upper Atmosphere, held at San Antonio under auspices of School of Aviation Medicine, USAF, November, 1951

Strughold, Hubertus: "Life on Mars in view of Physiological Principles," special project report, Dept. of Space Medicine, School of Aviation Medicine, San Antonio, March, 1951

Strughold, Hubertus: "Physiological Considerations on the Possibility of Life under Extraterrestrial Conditions," in Space Medicine, see Marbarger

Stuhlman, Otto, Jr.: "An Introduction to Biophysics," Wiley, New York, 1943

Sutton, G. P.: "Rocket Propulsion Progress--A Literature Survey," Journal of American Rocket Society, New York, January-February, 1952

Swain, George F.: "Structural Engineering--Strength of Materials," McGraw-Hill, New York, 1924

Telkes, Maria: "Solar House Heating--A Problem in Heat Storage," in Heating and Ventilating, The Industrial Press, New York, May, 1947

Thompson, G. V. E.: "The Lunar Base," in Journal of British Interplanetary Society, London, March, 1951

Timoshenko, S.: "Theory of Plates and Shells," McGraw-Hill, New York, 1940

Tombaugh, Clyde: "Why Mars is Red," Science News Letter, 8 July 1950

Trefethen, Joseph M.: "Geology for Engineers," Van Nostrand, New York, 1949

Urey, Harold C.: "Structural and Geologic Considerations of Mars," Physical Review, 15 October 1950

von Braun, Wernher: "Mars Project," unpublished translation of manuscript 1950; published in Germany

von Braun, Wernher: "The Importance of Satellite Vehicles in Interplanetary Flight," in Journal of British Interplanetary Society, London, November, 1951

von Braun, Wernher: "Crossing the Last Frontier," in Collier's Magazine, Crowell-Collier Publishing Co., New York, 22 March 1952

Whipple, Fred L.: "Earth, Moon, and Planets," Blakiston, Philadelphia, 1941

Whipple, Fred L.: "Meteoritic Phenomena and Meteorites," paper delivered at Symposium, n.d.

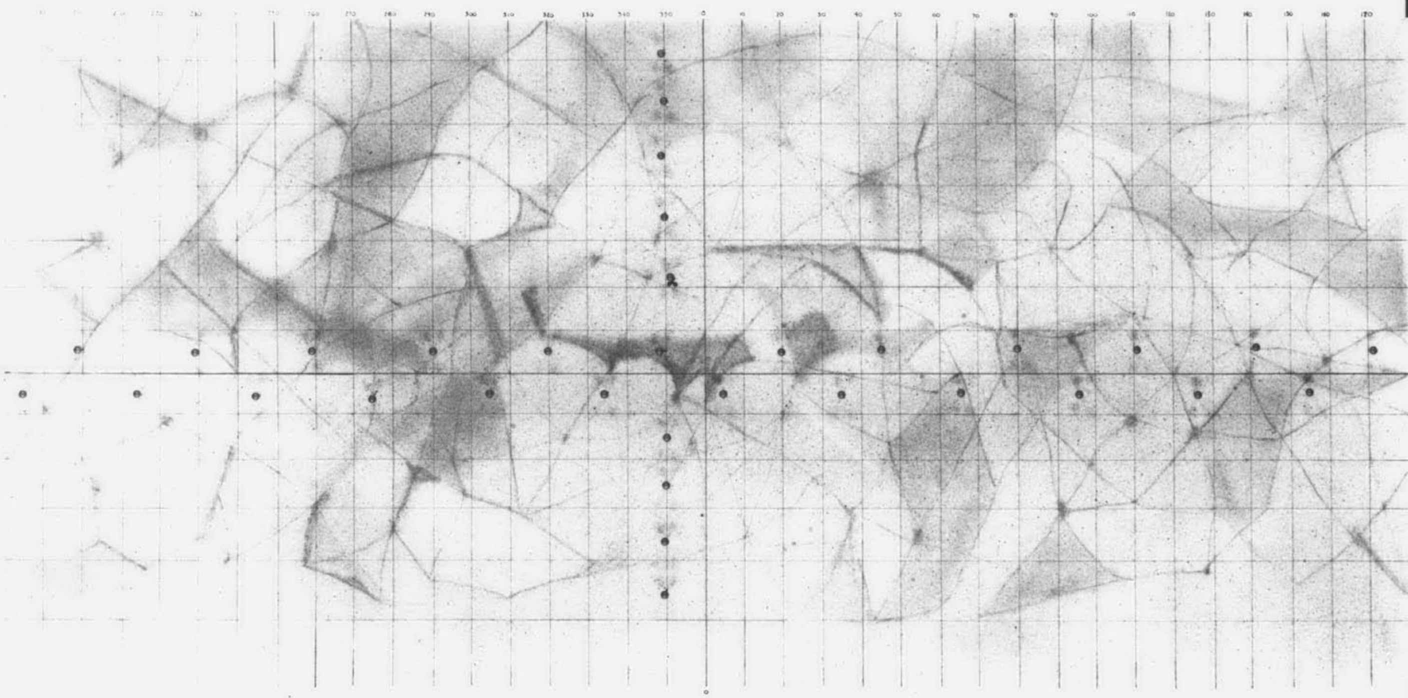
Wise, Joseph A.: "Roof Supported by Air Pressure," in Engineering News-Record, New York, 30 November 1944

Kuiper, Gerard P.: "The Atmospheres of the Earth and Planets," University of Chicago Press, 1949

Spitzer, Lyman, Jr.: "The Terrestrial Atmosphere above 300 km," incl. in Atmospheres of Earth and Planets, see Kuiper

Spitzer, Lyman, Jr.: "Interplanetary Travel Between Satellite Orbits," Journal of British Interplanetary Society, London, November, 1951

A PROTOTYPE TECHNICAL RESEARCH CENTER ON MARS



LOCATION OF BASES AND
WEATHER STATIONS

ALFRED WALLACE MOFFETT
MASTER IN ARCHITECTURE
JUNE 195[illegible]

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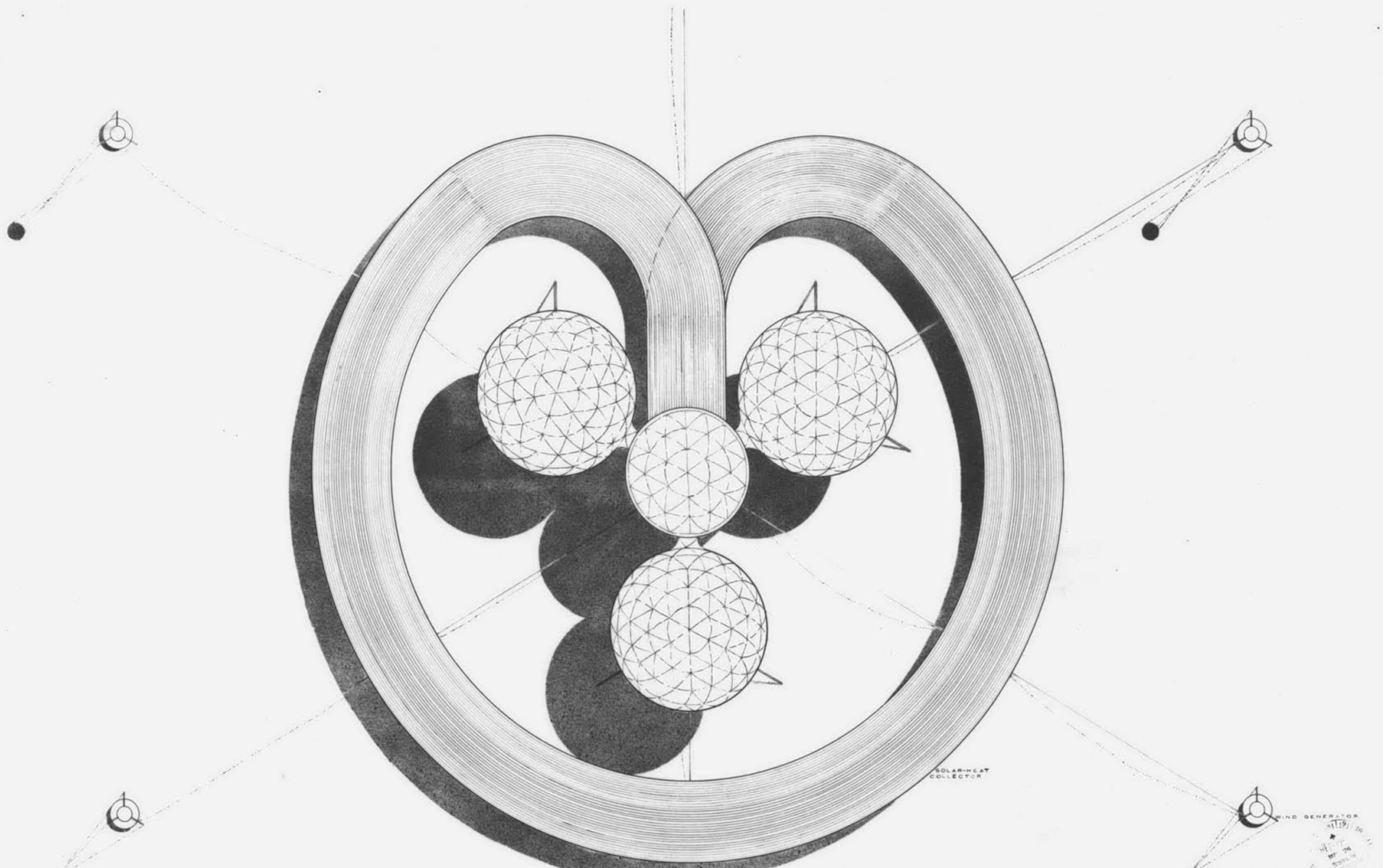

GENERAL LAYOUT OF THE
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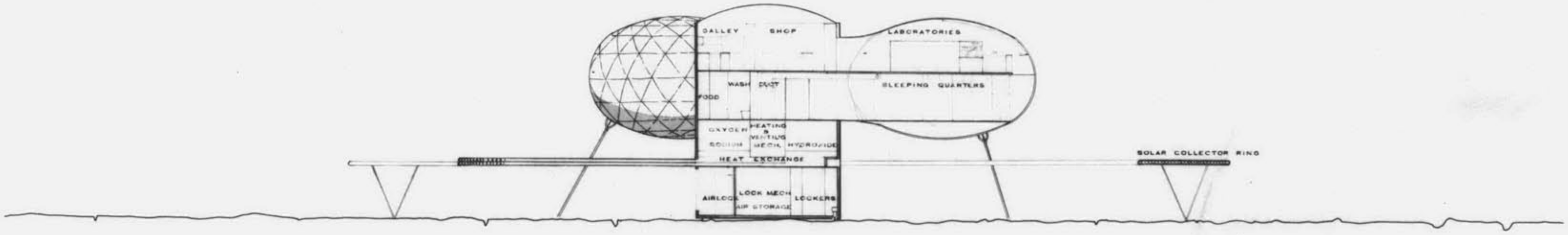
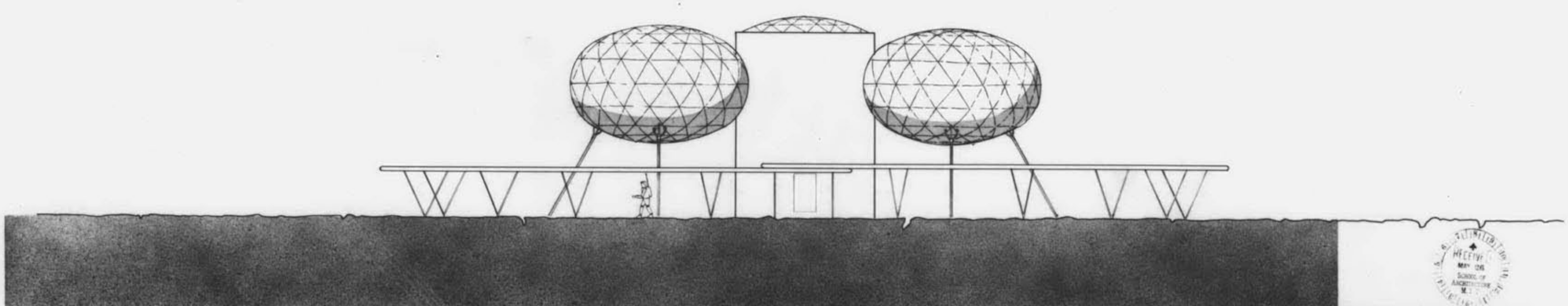
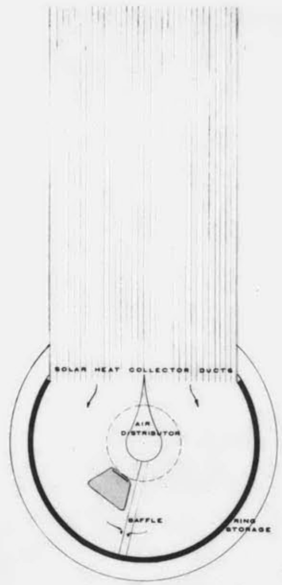




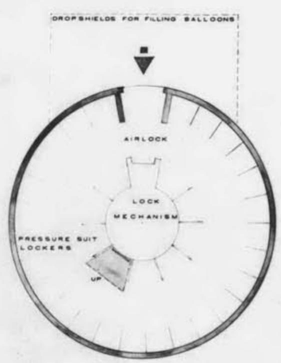
ELEVATION AND SECTION
TECHNICAL RESEARCH
CENTER

ALFRED WALLACE MOFFETT
MASTER IN ARCHITECTURE
JUNE 195

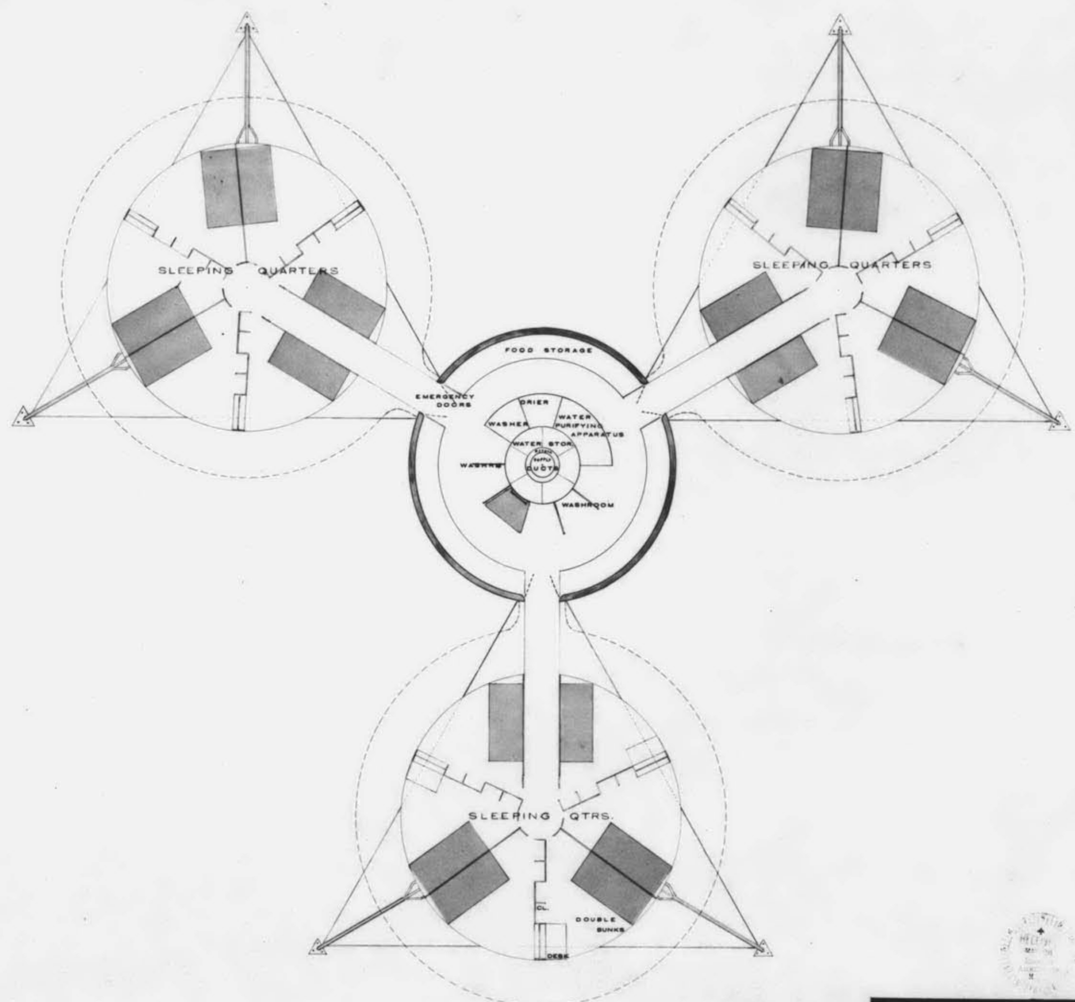
3



SECOND LEVEL ¼"



FIRST LEVEL ¼"



THIRD LEVEL ¼"

FLOOR PLAN 1ST 2ND 3RD LEVEL
TECHNICAL RESEARCH
CENTER

ALFRED WALLACE [illegible]
MASTER IN ARCHITECTURE
JUNE 195[illegible]

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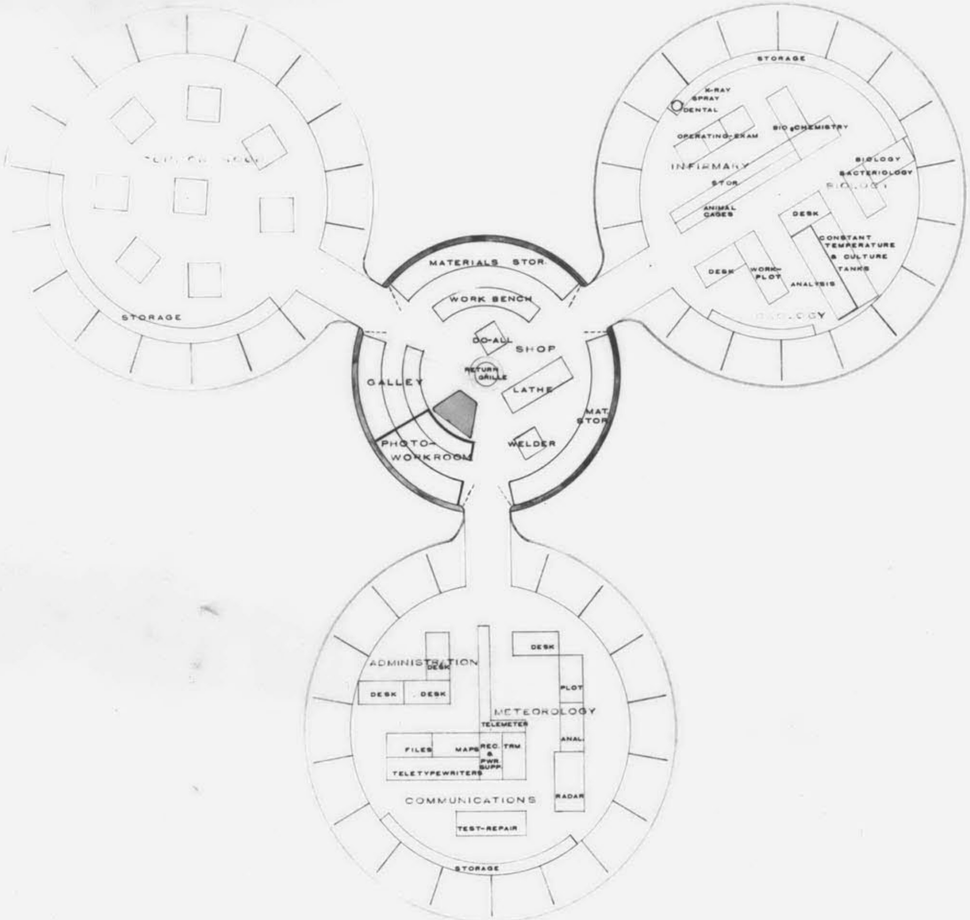
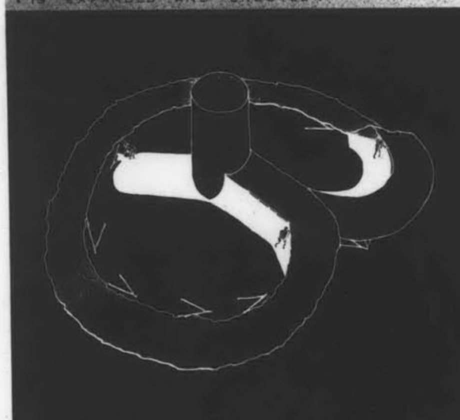


CONSTRUCTION PROCEDURE

1 SETTING PORTION OF LANDING CRAFT. ERECT AFTER ARRIVAL

2 AFTER LEVELING, THE SOLAR COLLECTOR RING IS EXPANDED AND ERECTED.



FLOOR PLAN-4TH LEVEL
TECHNICAL RESEARCH
CENTER

ALFRED WALLACE MOFFETT
MASTER IN ARCHITECTURE
JUNE 1952

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3 THE LIVING [illegible] WITH THE STRUTS [illegible] CABLES

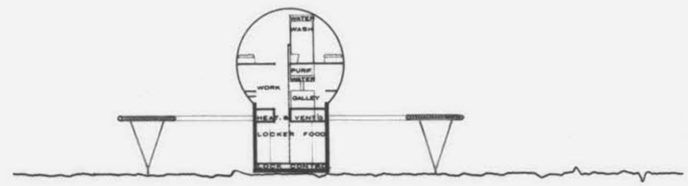
4 THE FINAL [illegible] INSIDE IS SETTING UP [illegible]

THIRD LEVEL

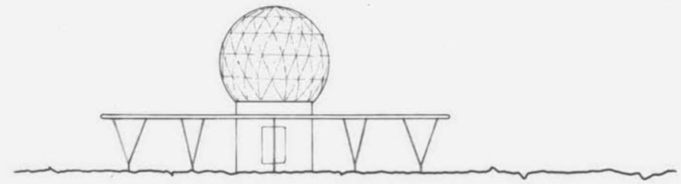
SECOND LEVEL

HEAT EXCHANGE CHAMBER

FIRST LEVEL ¼"



SECTION ⅛"



ELEVATION ⅛"

PLANS SECTION ELEVATION
SUB-BASE
CONSTRUCTION PROCEDURE

ALFRED WALLACE MOFFETT
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JUNE 952

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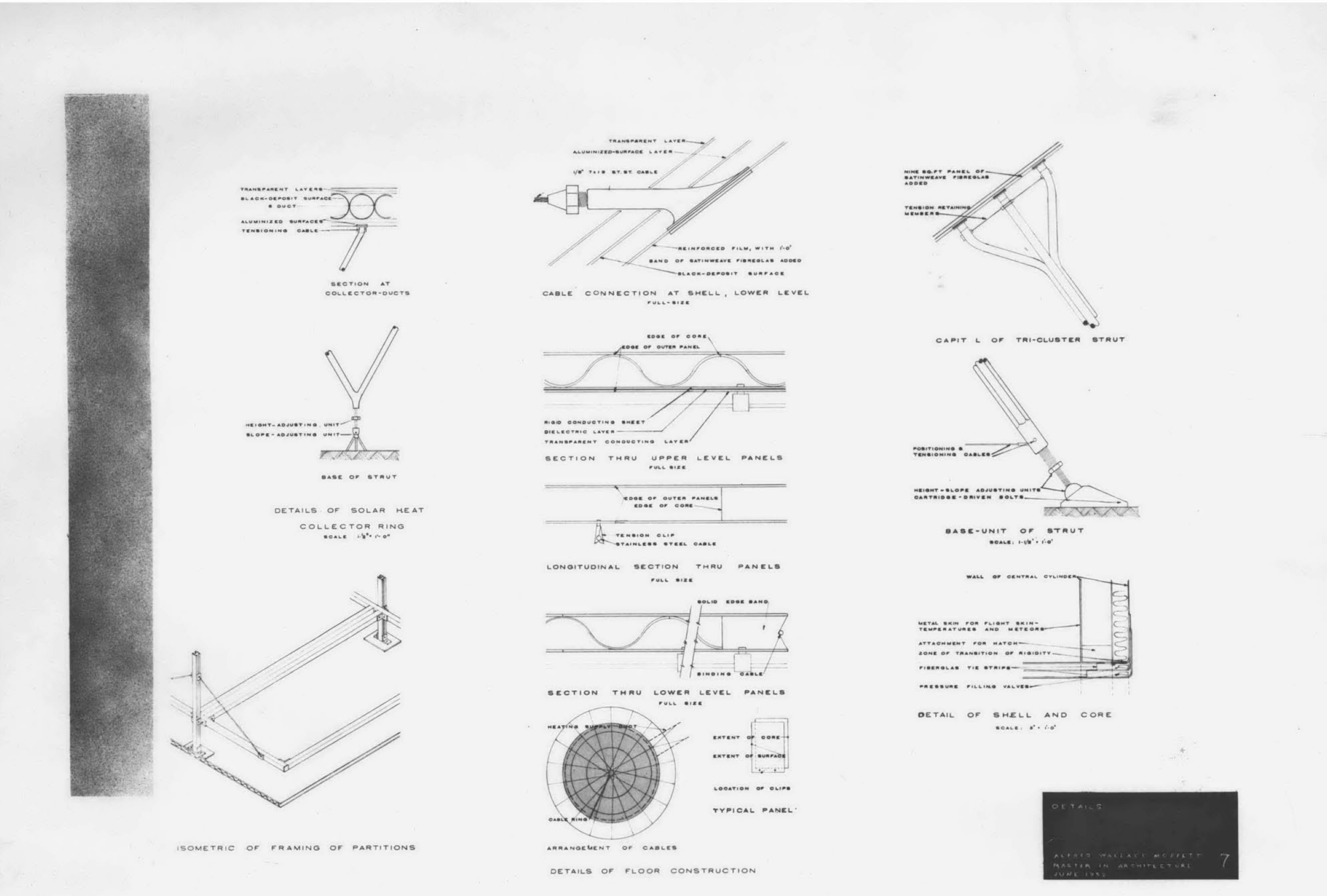
TRANSPARENT LAYERS
BLACK-DEPOSIT SURFACE & DUCT
ALUMINIZED SURFACES
TENSIONING CABLE
SECTION AT COLLECTOR-DUCTS
HEIGHT-ADJUSTING UNIT
SLOPE-ADJUSTING UNIT
BASE OF STRUT
DETAILS OF SOLAR HEAT COLLECTOR RING
ISOMETRIC OF FRAMING OF PARTITIONS
TRANSPARENT LAYER
ALUMINIZED-SURFACE LAYER
REINFORCED FILM, WITH 1'-0"
BAND OF SATINWEAVE FIBREGLAS ADDED
BLACK-DEPOSIT SURFACE
CABLE CONNECTION AT SHELL, LOWER LEVEL
FULL-SIZE
EDGE OF CORE
EDGE OF OUTER PANEL
RIGID CONDUCTING SHEET
DIELECTRIC LAYER
TRANSPARENT CONDUCTING LAYER
SECTION THRU UPPER LEVEL PANELS
FULL SIZE
EDGE OF OUTER PANELS
EDGE OF CORE
TENSION CLIP
STAINLESS STEEL CABLE
LONGITUDINAL SECTION THRU PANELS
FULL SIZE
SOLID EDGE BAND
BINDING CABLE
SECTION THRU LOWER LEVEL PANELS
FULL SIZE
HEATING SUPPLY DUCT
CABLE RING
ARRANGEMENT OF CABLES
EXTENT OF CORE
EXTENT OF SURFACE
LOCATION OF CLIPS
TYPICAL PANEL
DETAILS OF FLOOR CONSTRUCTION
NINE SQ.FT PANEL OF SATINWEAVE FIBREGLAS ADDED
TENSION RETAINING MEMBERS
CAPIT L OF TRI-CLUSTER STRUT
POSITIONING & TENSIONING CABLES
HEIGHT-SLOPE ADJUSTING UNITS
CARTRIDGE-DRIVEN BOLTS
BASE-UNIT OF STRUT
WALL OF CENTRAL CYLINDER
METAL SKIN FOR FLIGHT SKIN-TEMPERATURES AND METEORS
ATTACHMENT FOR HATCH
ZONE OF TRANSITION OF RIGIDITY
FIBERGLAS TIE STRIPS
PRESSURE FILLING VALVES
DETAIL OF SHELL AND CORE
DETAILS
MASTER IN ARCHITECTURE
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